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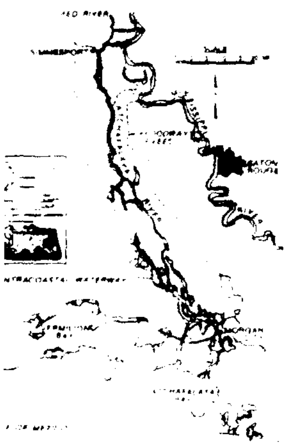

HYDRAULICS LABORATORY

TECHNICAL REPORT HL-82-15

(2)

THE ATCHAFALAYA RIVER DELTA

Report 1

A Plan For Predicting Delta Evolution

by

William H. McAnally, Jr., Samuel B. Heltzel
Barbara P. Donnell

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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13. ABSTRACT *(Maximum 200 words)*
Atchafalaya Bay, Louisiana, contains one of the world's most actively growing deltas. Growth of that delta will affect the physical environment of the area, navigation projects, and flood control projects. The hydraulic system in which the delta occurs contains riverine, lacustrine, estuarine, and marine environments, along with extensive wetlands. Cohesive and noncohesive sediment movement is subject to tidal and riverflow influences, as modified by winds, waves, and density currents. A plan was constructed that would permit delta evolution for the next 50 years to be predicted along with anticipated impacts of that delta growth. The plan included multiple approaches to predict delta growth, ranging from simple extrapolation to complex numerical modeling.

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Atchafalaya Basin System description
Modeling methods
Solution requirements and methods
Study design
Technical approach

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PREFACE

This plan was developed during the period August 1977 to September 1978 at the US Army Engineer Waterways Experiment Station (WES) with funding provided by the US Army Engineer District, New Orleans (LMN).

Personnel of the WES Hydraulics Laboratory performed the work described herein under the direction of Messrs. H. B. Simmons, former Chief of the Hydraulics Laboratory; F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief of the Hydraulics Laboratory, and former Chief of the Estuaries Division, Hydraulics Laboratory; M. B. Boyd, Chief of the Hydraulic Analysis Division, Hydraulics Laboratory; and G. M. Fisackerly, Chief of the Estuarine Processes Branch, Estuaries Division. Messrs. S. B. Heltzel, Estuarine Engineering Branch, Estuaries Division; J. V. Letter, Jr., Chief, Estuarine Simulation Branch, Estuaries Division; W. H. McAnally, Jr., Chief of the Estuaries Division; and W. A. Thomas, Waterways Division, Hydraulics Laboratory, developed the plan. Other WES personnel making major contributions were Messrs. S. A. Adamec, Information Technology Laboratory, WES; S. S. Grogan, Estuaries Division; C. J. Huval, Waterways Division; E. B. Pickett, Hydraulics Laboratory (retired); and D. T. Resio, formerly of the Hydraulics Laboratory; and Drs. J. R. Houston, Coastal Engineering Research Center, WES; V. E. LaGarde III, Environmental Laboratory, WES; F. M. Neilson, Hydraulic Analysis Branch, Hydraulic Structures Division, Hydraulics Laboratory; C. L. Vincent, Coastal Engineering Research Center; and R. W. Whalin, WES. This report was prepared by Messrs. McAnally and Heltzel and Ms. B. P. Donnell, Estuarine Simulation Branch. The bibliography was compiled by Ms. C. J. Coleman, Estuarine Processes Branch.

Mr. B. J. Garrett, LMN; Dr. D. C. Raney of the University of Alabama, Tuscaloosa, AL; and Mr. R. H. W. Cunningham, Dr. W. G. McIntyre, and their associates at the Center for Wetland Resources, Louisiana State University, Baton Rouge, LA; made many significant contributions to development of the plan. The useful comments and recommendations of the panel of experts who reviewed the draft plan are gratefully acknowledged: Drs. R. G. Dean, J. G. Gosselink, H. D. Hoese, G. H. Keulegan, C. R. Kolb, R. B. Krone, D. W. Pritchard, H. H. Roberts, Professor R. O. Reid, and Mr. F. B. Toffaleti.

During Phase II of this investigation, a panel of expert consultants met with the project team at regular intervals to review progress and recommend

changes in approach. Non-Corps members of that panel were Drs. C. R. Kolb and R. B. Krone, Mr. Fred Toffaleti, and Mr. L. R. Beard. Corps participants were Messrs. F. M. Chatry, C. W. Soileau, B. J. Garrett, H. E. Walker, and L. F. Cook.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
fathoms	1.8288	metres
feet	0.3048	metres
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres
square miles	2.589998	square kilometres
tons (2,000 pounds, mass)	970.1847	kilograms

THE ATCHAFALAYA RIVER DELTA

A PLAN FOR PREDICTING DELTA EVOLUTION

PART I: INTRODUCTION

Objective

1. The overall objective of this effort was to provide a set of tools to predict the evolution of the Atchafalaya River delta and the effects of that evolution. This report describes the first step toward developing a set of tools--formulation of a plan to define the primary physical processes of the Atchafalaya Bay system and to integrate those processes into reliable predictions of delta growth and bay response.

Background

2. Approximately 30 percent of the combined flows of the Mississippi and Red Rivers passes through the Atchafalaya River basin. This flow carries about 72 million cubic yards* of suspended sediment annually. This sediment, which in the past was deposited in the lake and overbank areas to the north of Morgan City, is now passing through lower Atchafalaya River and Wax Lake Outlet into the bays and marshes to the south. Deposition of the sediment has caused the demise of the Grand and Six Mile Lakes system and emergence of a subaerial delta in Atchafalaya Bay expanding across the bay.

3. Progression of the delta is (a) creating new marsh areas, (b) altering the existing wetland habitats, (c) modifying the water quality within Atchafalaya Bay and adjacent bays, (d) affecting flood flow lines at Morgan City, Berwick, and northward, and (e) increasing the need for maintenance dredging, especially during high-water years.

4. A concerted effort to develop a comprehensive plan for predicting the Evolution Atchafalaya Bay was made at a symposium held by the U. S. Army Engineer District, New Orleans (LMN), during 24-25 June 1976.

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* A table of factors for converting U.S. customary units of measurement to metric (SI) units is presented on page 4.

5. LMN considered their research needs for Atchafalaya Bay to be:

a. Determination of the behavior of fluvial sediment as the river flows into a saltwater environment by mathematical model or analog with prototype deltas.

b. Prediction of the effect of various policies for placement of dredged material in the bay as it relates to building a channel which will be eventually self-maintaining, to optimal marsh building, and to interaction of the deltas of Lower Atchafalaya River and Wax Lake Outlet.

c. Knowledge of the effect of various distributions of flow between Lower Atchafalaya River and Wax Lake Outlet.

d. Development of a mathematical model for bays and sounds to model sediment movement, circulation patterns, saltwater-sediment interactions, and changes in water quality."

6. In response to a request made at the meeting for proposed plans, the U. S. Army Engineer Waterways Experiment Station (WES) proposed an approach consisting of the following overlapping phases:

a. Phase I: Plan Development

(1) Collect and review available prototype data on Atchafalaya Bay

(2) Plan a supplemental prototype data collection program.

(3) Study the bay and the phenomena of interest to define modeling constraints. Design models and develop methods of solution.

b. Phase II: Plan Implementation

(1) Conduct prototype data collection programs.

(2) Construct models; verify to prototype data and other models.

(3) Conduct model tests to determine effects of various ultimate and intermediate stages of bay development. Define characteristics of system, potential problems, and potential solutions.

c. Phase III. Future Evaluations and Monitoring

(1) Conduct model tests to develop and verify best designs of improvement works, define their immediate and long-range effects

(2) Continue selected portions of prototype data collection program to determine compliance with projections, detect problems, and provide input for model updating.

(3) Conduct intermittent model tests to update predictions based on recent prototype developments and advances in

model technology. Develop solutions for new problems and show long-term effects.

The proposed approach was approved 2 June 1977 by Headquarters, US Army Corps of Engineers, and work commenced on Phase I on 1 September 1977. In July 1978, this report was completed in draft form. Work began on Phase II on 15 Jan 1979. This report remained in draft form until 1988, when completion of Phase II and the first portion of Phase III permitted final revisions to be made. The description of the Atchafalaya system was not updated to reflect changes occurring since 1978.

Approach

7. The essential questions to be addressed were:

<u>a</u>. For existing conditions and no actions other than those already practiced (i.e., maintenance of navigation channels), how will the delta evolve over the short-to-medium term (10-15 years) and long term (>10 years)?

<u>b</u>. How will its evolution affect:

(1) Flood stages.

(2) Maintenance dredging of the navigation channels.

(3) Flow distribution between lower Atchafalaya River and Wax Lake Outlet.

(4) Salinity in the Atchafalaya Bay system.

<u>c</u>. What will be the impact of various alternatives on all of the above? Possible alternatives to the no-action case include:

(1) Additional levees.

(2) Structures to alter flow distribution between lower Atchafalaya River and Wax Lake Outlet.

(3) A jetty in the bay.

(4) Dredged material disposal techniques.

(5) Floodways bypassing Morgan City.

(6) New outlet(s) to the bay.

(7) Channel training works.

8. The approach used in developing this plan was one of reviewing basin and bay characteristics and available solution methods, then developing recommendations on methods of addressing the questions of paragraph 7. Literature reviews included previous model studies, reports on the delta's evolution, and LMN and other prototype data. The views of those familiar with the

Atchafalaya system were solicited. Reviews of modeling alternatives (hydrodynamic, sediment transport, and delta building) were conducted. With a basic understanding of Corps' objectives and pertinent characteristics of the Atchafalaya Floodway/Bay system, a comprehensive plan was designed to provide a framework in which all major processes affecting the questions of paragraph 7 could be addressed. This plan was reviewed by LMN and a panel of expert advisors. Their recommendations for revisions and implementation were then used to modify the plan.

9. During the implementation of Phase II, further revisions were made to the plan based on experience and advice of a panel of expert consultants. A panel of Corps and non-Corps experts (see preface) met at regular intervals to review progress and recommend changes to the work.

Publications

10. The work described in this plan is reported in the following series of WES technical reports with the same and general title number ("The Atchafalaya River Delta", TR HL-82-15):

a. Report 1: A Plan for Predicting Delta Evolution

b. Report 2: Field Investigations (four sections)

c. Report 3: Extrapolation of Delta Growth

d. Report 4: Generic Analysis of Delta Development

e. Report 5: Quasi-2-Dimensional Modeling

f. Report 6: Interim Summary Report of Growth Predictions

g. Report 7: Analytical Analysis of the Development of the Atchafalaya River Delta

h. Report 8: Numerical Modeling of Hurricane-Induced Storm Surge (2 volumes)

i. Report 9: Wind Climatology

j. Report 10: Wave Hindcasts (2 volumes)

k. Report 11: Two-Dimensional Modeling

l. Report 12: Two-Dimensional Modeling of Alternative Plans and Impacts on the Atchafalaya Bay and Terrebonne Marshes

m. Report 13: Summary Report of Delta Growth Predictions

PART II: DESCRIPTION OF THE ATCHAFALAYA BASIN/BAY SYSTEM

11. The riverine/lacustrine environment of the Atchafalaya Basin and the coastal/estuarine environment of the Atchafalaya Bay have been undergoing significant modification as a result of sedimentation processes. These sedimentation processes have manifested themselves in the demise of Grand and Six Mile Lakes systems which are being reduced in area at a rate of 3 square miles per year (Cartmill, 1974) and the emergence of a subaerial delta in Atchafalaya Bay expanding across the bay at a rate of 5.5 to 6.5 square miles per year (Shlemon and Gagliano, 1972; and Shlemon, 1975). The sedimentation processes in these areas are similar; however, the regimes into which the sediment is placed are quite different. The basin regime, affected by river currents, winds, and barge movement, is rather mild compared with a vigorous bay regime influenced by river currents, tidal, wind, and wave influences.

12. Because of the significant impact the development of the basin has had on the present configuration of the bay, the information presented in this section will proceed from the development of the basin out into the bay and then describe the major influences shaping the bay. It is the purpose of this section to discuss the evolutionary history of the Atchafalaya River basin and bay and the significant influences modifying the bay. The information gathered during this portion of the effort formed the basis for evaluating the phenomena to be modeled.

General Description

13. The Atchafalaya River Basin, located in south central Louisiana, is extremely flat and low with numerous channels and lakes, and is situated between the existing Mississippi River, Bayous LaFourche and Terrebonne on the east, and Bayou Teche on the west (Figure 1). The Atchafalaya River carries a portion of the Mississippi River flow and is a vital part of LMN's flood protection plan for the city of New Orleans and surrounding areas. It extends from just downstream of the confluence of the Red and Old Rivers, near Simmesport, in a southerly direction to the Gulf of Mexico near Morgan City, a river distance of about 140 miles. The Atchafalaya Basin floodway, about 15 miles wide, is confined by the east and west protection levees and terminates in two uncontrolled outlets to the Gulf of Mexico--a natural one via The

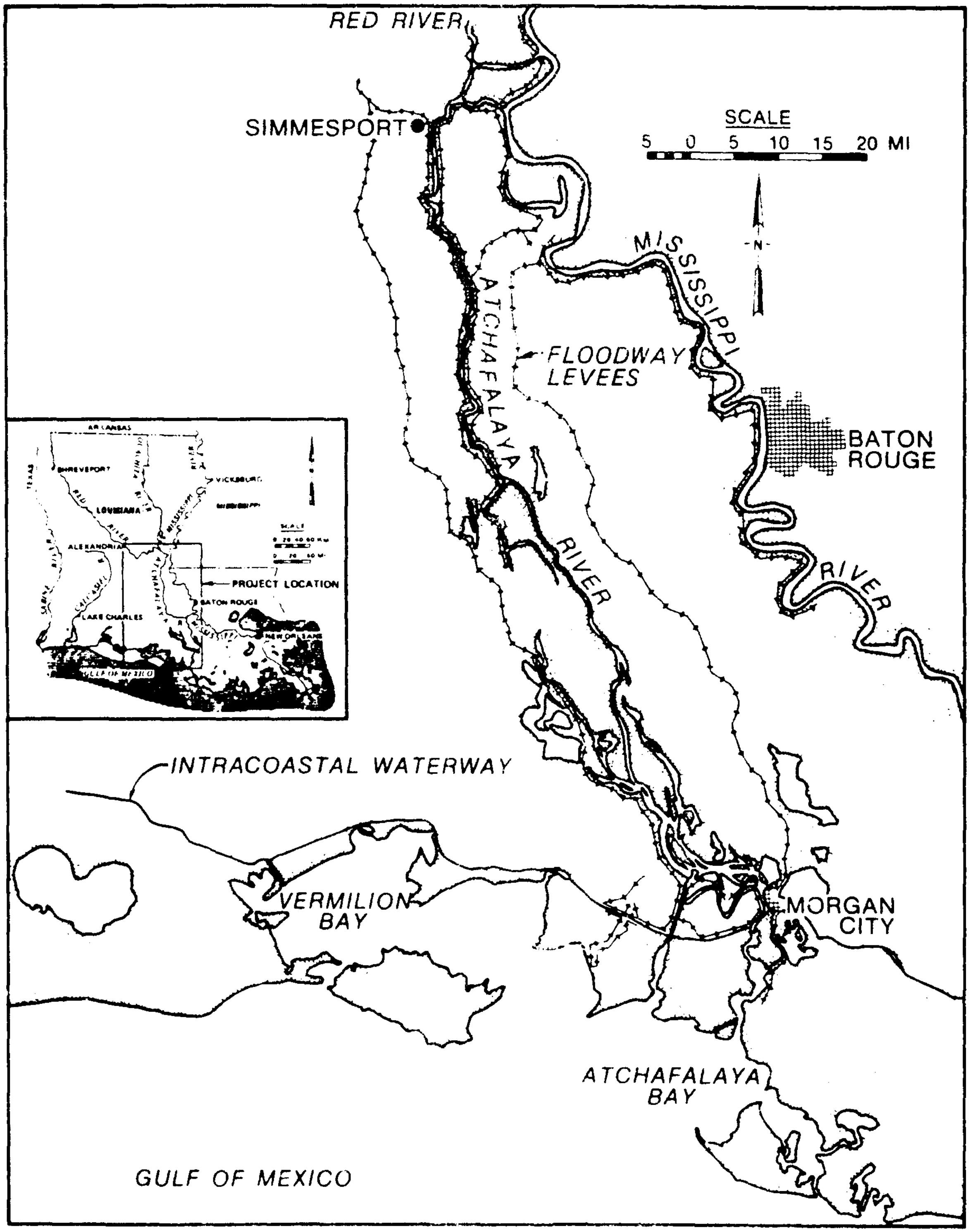

Figure 1. Project location

Lower Atchafalaya River and Berwick Bay, and the Wax Lake Outlet, a connection dredged between Six Mile Lake and Atchafalaya Bay in 1942.

14. The Morganza and West Atchafalaya Floodways, in the upper basin on opposite sides of the Atchafalaya River, extend downstream to the end of the levee system along the Atchafalaya River below Krotz Springs, where they merge into a single floodway. The Atchafalaya River and floodways pass one-half of the 3,000,000-cfs project design flood of the Mississippi-Red-Atchafalaya Rivers system. Storage potential of the Atchafalaya Basin permits an additional 30,000 cfs to flow into it. This design flood flow of 1,530,000 cfs is to be routed to the Gulf of Mexico by passing 930,000 cfs from the Red River backwater area into the Atchafalaya Basin at the latitude of Simmesport. Of this latter flow, a discharge of 680,000 cfs is to enter the Atchafalaya basin through the main channel of the Atchafalaya River, and a discharge of 250,000 cfs is to pass through the West Atchafalaya Floodway. The remaining 600,000 cfs will flow through the Morganza Control Structure into the Atchafalaya Basin Floodway. Due to storage effects in the floodways, a flow of 1,500,000 cfs will pass through the floodway south of Krotz Springs.

15. The Gulf Intracoastal Waterway (GIWW) crosses the lower basin below Morgan City. One route proceeds north inside the east levee and leads to the Baton Rouge area. An Atchafalaya River channel is maintained for barge traffic to and from the Mississippi River via Old River.

16. The area incorporating Atchafalaya Bay has as its northern boundary the natural levee of the abandoned Teche Channel of the Mississippi River. The area is an extensive interconnecting system of tidal bays which include Atchafalaya, East Cote Blanche, West Cote Blanche, and Vermilion Bays. This system opens to the gulf along the 27-mile southern boundary of the Atchafalaya Bay and also through a narrow tidal inlet, Southwest Pass, leading to Vermilion Bay. Dimensions of this system are summarized below:

Length of Shoreline, miles	
Marsh Island (gulf side)	20
Vermilion Bay	+80
West-East Cote Blanche Bay	+56
Atchafalaya Bay	+40
Pt. Au Fer Island-Fourleague Bay	+40

Water Areas and Volume

Area	Square Miles	Average Depth, ft	Volume cu ft
Vermilion Bay	161	7	3.14×10^{10}
West Cote Blanche Bay	117	6	1.97×10^{10}
East Cote Blanche Bay	76.2	5	1.06×10^{10}
Atchafalaya Bay	232	5	3.25×10^{10}
Fourleague Bay	28	4	3.12×10^{9}

(from Badgley et al., 1970)

17. This coastal region has been divided into two distinct regions based on origin and physical characteristics. The area east of Vermilion Bay and occupying approximately two-thirds of this coastal area has been named the Deltaic Plain, which is the site of the various delta systems. The area west of Vermilion Bay has been named the Chenier Plain and developed from river sediment carried westward by longshore currents in the Gulf of Mexico (Coleman, 1966).

18. Atchafalaya Bay is 33 miles long, 8 miles wide, and has an area of 233 square miles. Marshes form its northern and eastern borders. The elevation of these marshes is approximately 2 to 3 ft above mean gulf level (mgl) for a considerable distance back from the shoreline of the bay. The southern boundary of the bay is the Point Au Fer Shell Reef, an oyster reef, which extends from Point Au Fer on the east side of the bay to within 5 miles of Marsh Island on the west side. This oyster reef is an active area for shell dredging and no longer has extensive subaerial exposure. Although Marsh Island is generally quite low (about 2 to 3 ft above mgl), the south side of the island is bounded by a coastal ridge or chenier that rises to an elevation of about 5 to 6 ft above mgl.

19. The combined Atchafalaya Basin/Bay area once formed an estuary about 100 miles long and 40 miles wide open to the Gulf of Mexico and extending northward as far as the latitude of Baton Rouge. Russell (1967) concisely describes the deltaic extinction of this large estuary in saying: "Extremely old channels of the Mississippi led to its northern shore. About 4000 years ago, the Mississippi established a course it retained for more than a thousand years, close to its western valley wall. The Teche-Mississippi pushed its natural levees and delta eastward across the Atchafalaya embayment, converting it into a huge estuary. Later the Mississippi diverted to its existing course

along its eastern valley wall. Natural levee plus delta growth soon completed the barricade, isolating Lake Atchafalaya from the gulf. The lake had maximum areal extent at that time. Three outlets were established across the Teche barrier to the south, and the intrusion of gulf water accounted for brackish-water fauna that thrived in the seaward part of the lake. Sediments contributed by small rivers to the west, the Red and Atchafalaya Rivers to the north, and crevasses from the Mississippi to the east led to the eventual demise of this large system." U. S. Army Corps of Engineers measurements show that the present lakes are rapidly being filled and that several lakes are only a quarter of their pre-1917 size (Fisk, 1951, and Garrett et al., 1969). Between 1963 and 1967, deposition averaged 0.7 foot per year. More sediments will be transported into Atchafalaya Bay as these lake basins are completely filled.

Review of Pertinent Literature

20. An abundance of literature has been published on the Atchafalaya system. Fisk (1951) published a comprehensive history of the Atchafalaya system in which he predicted the eventual recapture of the Mississippi by the Atchafalaya system. Thompson (1955) presented a detailed study of the recent sediments in the Atchafalaya system and discussed the marine processes helping to shape the Atchafalaya Bay terrain. Garrett et al. (1969) presented a comprehensive review of the Atchafalaya Bay and actually made predictions on the amount of new land area that could be created in the bay and on the adjacent shelf by the Atchafalaya delta in the next 50 years. Shlemon and Gagliano (1972) and Shlemon (1975) documented the development of the bay from 1952-1972 with references to the pre-1952 deposition. Cratsley (1975) made a rather extensive study of the Atchafalaya system, studying sedimentation in the bay and the sediment environment. The U. S. Army Corps of Engineers (1974) prepared a preliminary draft environmental impact statement on the Atchafalaya Basin Floodway. Roberts et al. (1978) have presented additional information on the subaerial development of the Atchafalaya Bay, the major delta growth being attributed to the extreme flood flows of 1973-1974.

Basin Deposition and Delta Growth

21. Grand and Six Mile Lakes was a large open water body subsequent to 1917. By 1930 a small delta had developed in the northern end of Grand Lake. The open water area of Grand Lake was reduced to about one-third the pre-1930 area between 1930 and 1944. During the period 1944 to 1960, the remainder of Grand Lake and most of Six Mile Lake were filled. The effectiveness of the lakes as a settling basin for the coarse traction of the sediment has been shown by analysis of bed samples collected along the river channel. According to Fisk (1951), deltaic deposition which has been taking place in Grand Lake for more than four centuries has produced an extensive subaerial delta that now fills all but a small portion of the prehistoric lake. Insignificant changes occurred in the lakes over the 15 years following 1960. The lower basin is now occupied by an active river channel connecting the natural lower Atchafalaya River outlet and the Wax Lake Outlet.

22. The Atchafalaya River levees in the upper basin have allowed the channel to become more efficient. This has resulted in a stage reduction in the upper basin and an increase in bank caving and the ability of the river to transport sediment. It appears that this sediment load was mainly deposited in the basin until about 1952 when sedimentation became visually evident in the delta. Cratsley (1975) reported that insignificant bathymetric change occurred in the Atchafalaya Bay until the 1950's; his comparison was with an 1858 survey. Thompson (1955) substantiated this in an earlier work by saying that in spite of the large sediment supply to the system, virtually all of the sediment was bypassing the bay and moving into the Gulf of Mexico. This was indicated by the small amount of change that occurred in the topography of the bay floor according to comparison of the Coast and Geodetic Survey hydrographic surveys of 1858-1859 and 1934-1935 and also by cores taken in the bay floor in 1950-1951. Thompson (1955) also states that the only significant changes that occurred in the 76-year interval between the surveys were adjacent to Point Au Fer Shell Reef on the seaward side of the bay where as much as 3 to 4 ft of sediment accumulated. The average rate of this accumulation exceeded one-quarter foot per year. Shlemon (1975) indicated that from 1952 to 1962 accelerated sedimentation in Atchafalaya Bay marked the beginning of a subaqueous delta. The sediments flowed into the bay from the Wax Lake and Atchafalaya River Outlets and were essentially clays and silty clays.

23. The subaerial delta development in Atchafalaya Bay has produced a highly visible delta that is a result of coarse sediment deposition. This is quite different from the types of sediment forming it in prior years. It has been postulated that this is a result of major flood events delivering sediments which were scoured from the lower basin fill deposits. This is evidenced by the abnormally high discharges during the period 1972-1975 which initiated the subaerial growth and caused it to evolve rapidly. Another reasonable assumption is that the velocities in the natural channel through the remnants of the prehistoric Grand and Six Mile Lakes are now sufficient to move the coarser grained material. Thus, the lower basin has lost some of its efficiency as a sediment trap.

24. Bathymetric data taken in 1976 and LANDSAT estimates for the same year indicate that approximately 12.7 square miles and 12.5 square miles, respectively, of the Atchafalaya Bay were eliminated because of subaerial delta development (Roberts et al., 1978). The initial subaerial exposures appearing in 1971-1972 were shoals composed largely of sediment derived from maintenance dredging of a 20- x 200-ft navigation channel from the Atchafalaya Bay Channel through Point Au Fer Shell Reef. There was also some development on the eastern side of the navigation channel unrelated to the dredging. Natural accretion of sediments appeared on both sides of the channel by 1973. Approximately 60 percent of the bay is 6 ft deep or less.

25. Since the early stages of delta development are subaqueous, it was not until 1973 that the delta became visible. Early accretion prior to 1952 consisted mainly of clays. In about 1952, general filling of the bay began and recently subaerial progradation and shoreline accretion have been initiated.

Significant Hydrodynamic Processes Shaping the Delta

Hydrologic influences

26. The flow in the Atchafalaya Basin is directly influenced by the amount received from the Mississippi River (via the Old River Structure) and the Red River. There is also some augmentation of this flow by the influence of rainfall and groundwater, which is a possible explanation as to why flow at the outlets is 4 percent greater than at Simmesport, Louisiana.

27. Generally the flow fits into a pattern of high and low regimes--the

high flow occurring in winter and spring and the low flow in the late summer and early fall. On the average, the monthly flow reaches a maximum of 325,000 cfs in April, decreasing to 73,000 cfs in September. Based on observations at Simmesport, the maximum flow of record is 700,000 cfs. During the period 1938-1972, the average annual flow in the Atchafalaya River at Simmesport, Louisiana, was 181,000 cfs. The Old River Structure, placed in operation in July 1963, limits diversion of the Mississippi flow to 30 percent of the combined discharge of the Red and Mississippi Rivers systems. Approximately 70 percent of the total flow through the Atchafalaya system is passed through the Atchafalaya River past Morgan City, with the remainder being passed by Wax Lake Outlet. Figure 2 is a plot of the average monthly discharge at the latitude of the outlets based on Simmesport, Louisiana, data for the period July 1963-July 1969.

28. Since the Wax Lake Outlet has a distinct gradient advantage to the Atchafalaya Bay, its cross section gradually enlarged from about 27,000 sq ft in 1963 to approximately 36,000 sq ft in 1975. This increased cross-sectional area, sediment deposition in the lower Atchafalaya River, and increased stages at the head of Wax Lake Outlet have altered the flow distribution between this outlet and the Atchafalaya River. The high flow passing through Wax Lake Outlet increased from 20 to approximately 30 percent and the percentage of low flows increased to approximately 45 percent in the late 1970's.

29. Compared with the last 30 years, 1973-1975 were abnormally high-water years. During 1973-75, flows averaged 313,000 cfs at Simmesport; peak flows of over 700,000 cfs were recorded in April 1973 and 600,000 cfs in April 1975 (USACOE, 1975). At Morgan City the peak flows exceeded 600,000 cfs during the Morganza floodway opening in 1973. This exceeded the normal 300,000-cfs peak flow during eight months of 1973-1975. The flows in the Wax Lake Outlet were also proportionally higher.

Meteorological effects

30. Many processes act on the Atchafalaya system with potential for causing substantial sediment redistribution. These include wind and its results in terms of water surface setup, setdown, and wind-generated currents and waves.

31. Meteorological data in the study area are very limited, restricted mainly to the airport at Calumet and a few additional stations. The data collected are in most cases not retained long. Therefore available local data

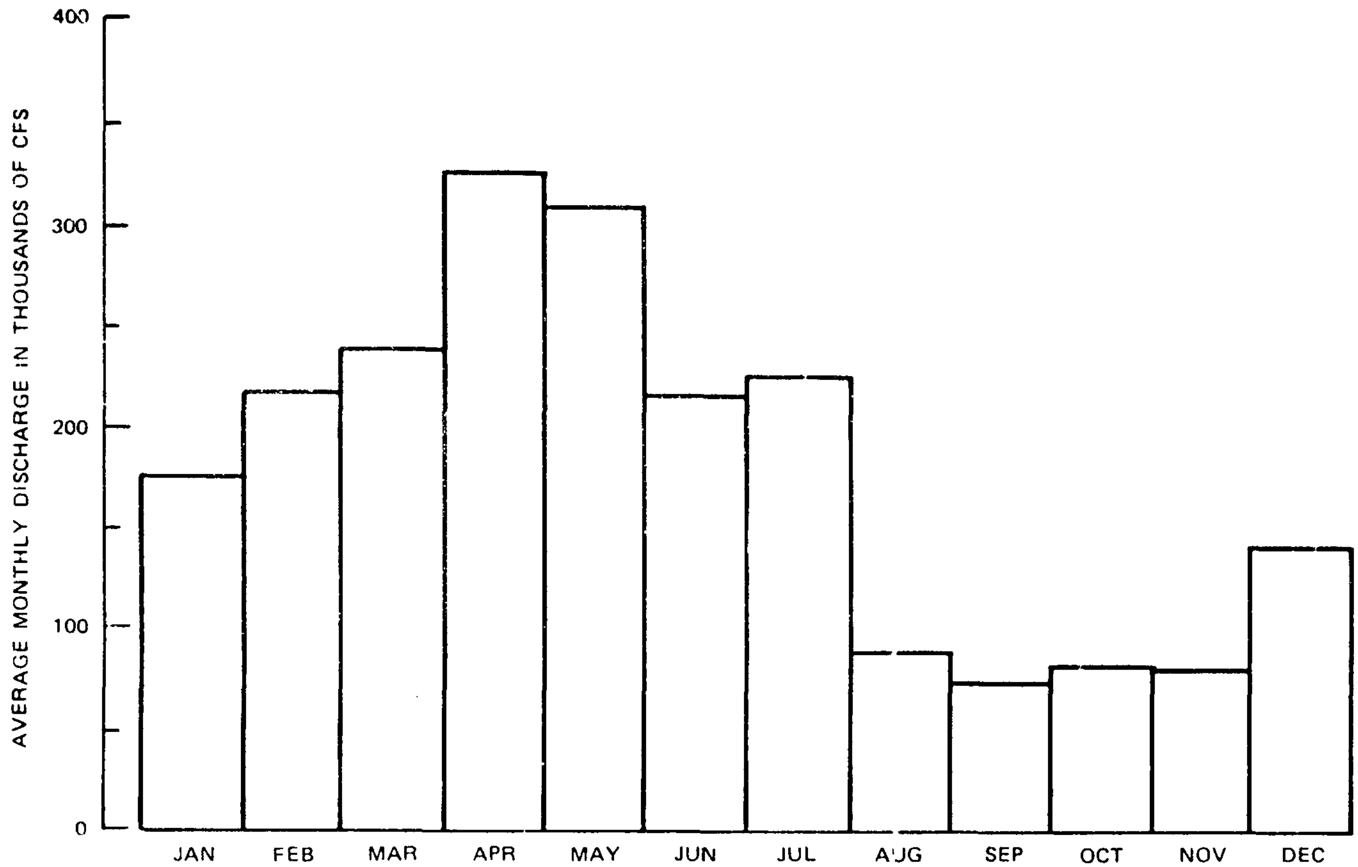

Figure 2. Average monthly discharge of the Lower Atchafalaya River for the period July 1963 to July 1969 (from Cratsley 1975)

does not provide a basis for any long-term analysis concerning expected trends, frequency of directions, etc.

32. Since the Atchafalaya Bay study area is located between the two long-term climatological stations of Lake Charles and New Orleans, it is generally considered reasonable to determine seasonal wind patterns combining long-term frequencies at these two stations; but since these are inland stations, this may not be a means to precisely reflect the conditions in the study area. These regional wind characteristics are summarized in Table 1 and Figures 3 and 4. Table 1 was generated by combining long-term frequencies at these two stations.

33. In this region, northerly winds are dominant in the winter, while southeasterly winds are the dominant spring regional circulation pattern. Southwesterly winds in the summer are a result of the influence of gulf high pressure. A high frequency of northeasterly winds is a result of weak continental high pressure in the fall (Cunningham, 1978).

34. With strong southerly winds, water surfaces along the coast of Louisiana will increase, resulting in movement of this water into the many bays, bayous, and canals. Frequently, marshes become flooded during periods of prolonged winds. The opposite of this effect is experienced with strong northerly winds, when tides as low as 2 ft below normal are common. Thus, marshes will be practically dry at such times.

35. Tropical storm systems, such as hurricanes and lesser tropical storms, frequently occur in the Atchafalaya Bay coastal region. The primary effects of these systems in the Atchafalaya area are twofold: large waves caused by the storms propagate further without breaking and strong currents are generated within the bay system as a result of bathymetry and local wind fields (Thompson, 1955). These storm systems vary in duration, e.g., hurricane tide and wave conditions seldom persist more than two days, and strong winds from the southeast commonly persist for three or four days or longer. These storm systems also vary in frequency, e.g., tropical storms and hurricanes that produce large storm tides in the Atchafalaya Bay coastal zone have a frequency of roughly one every two years, and several strong southeasters per year occur (Thompson, 1955).

36. The highest recorded storm tide in Atchafalaya Bay is 9 ft mgl, which occurred in August 1915. The hurricane moved parallel to the Louisiana coast, going inland near Galveston, Texas. Storm tides data in the

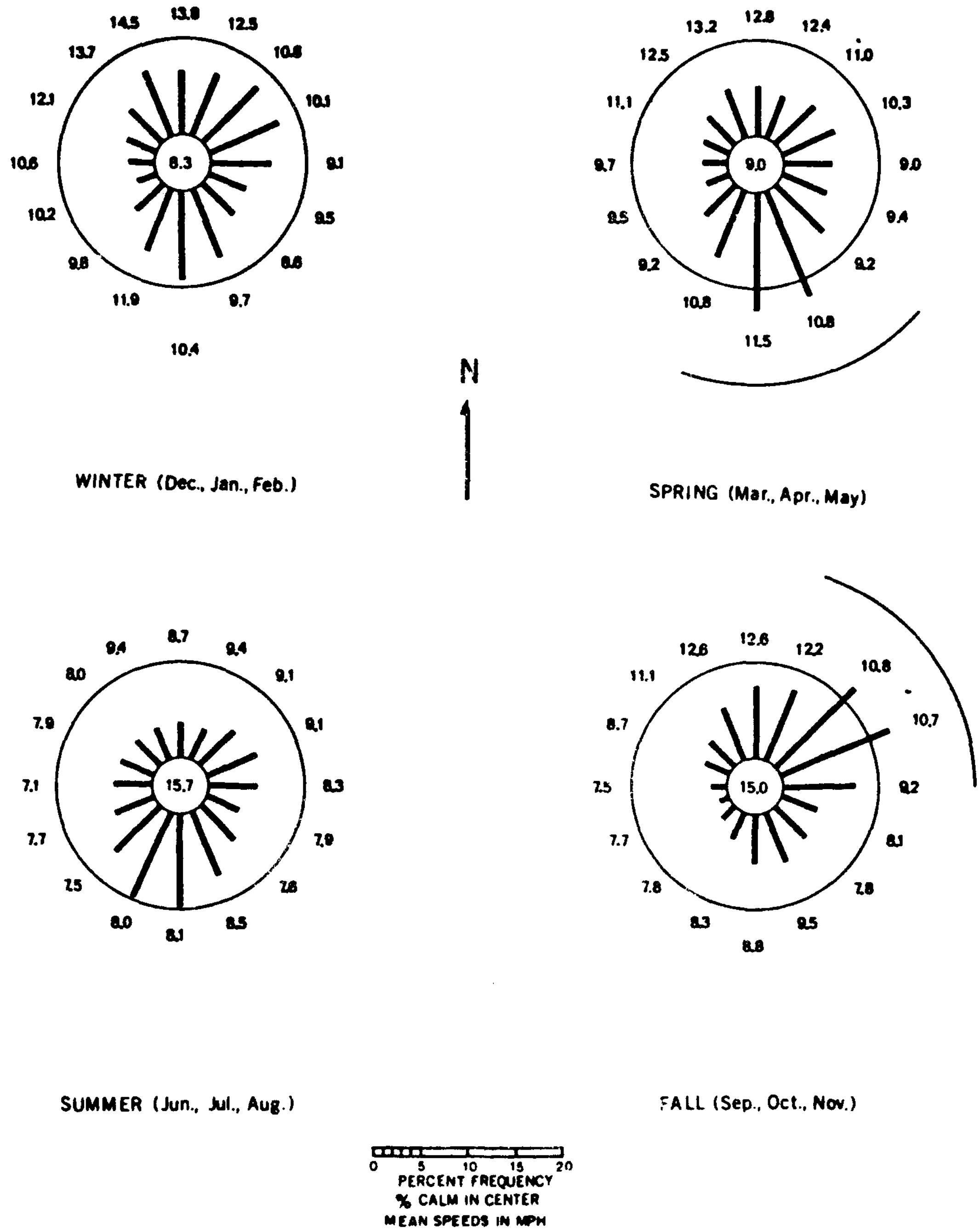

Figure 3. Seasonal wind roses, New Orleans, Louisiana, 1951-1960 (from Cunningham, 1978)

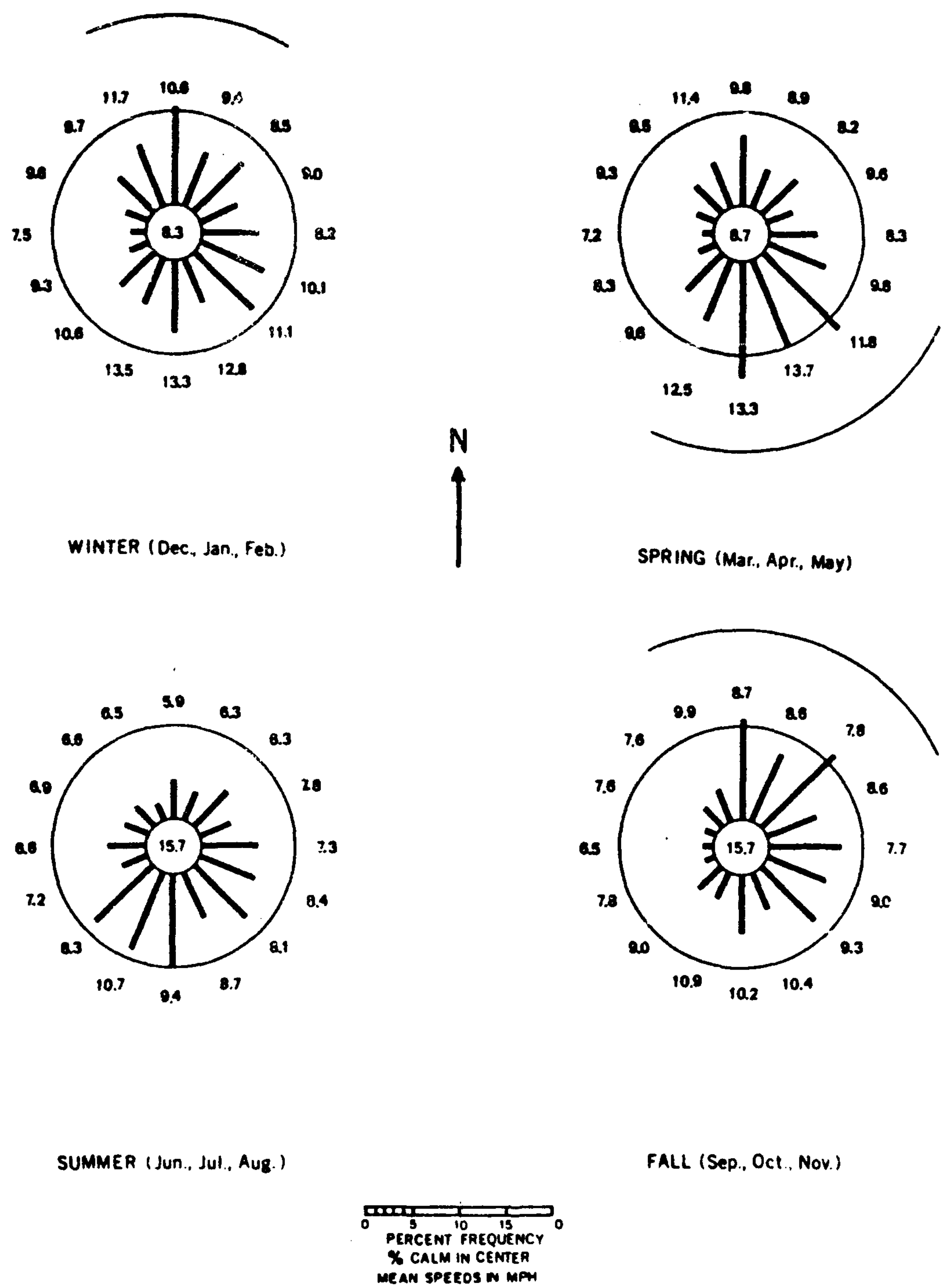

Figure 4. Seasonal wind roses, Lake Charles, Louisiana, 1951-1960 (from Cunningham, 1978)

Atchafalaya area are sparse--only five storms were measured during the period from 1900 to 1940 and only the 1915 storm tide was greater than 5 ft above the mean water of the bay.

37. The shell reefs in the western part of the bay or the dredged material banks part of the subaerial delta segment the bay into smaller units, which have decreased fetch and reduced wave heights. The shell reef and soft sediments forming the southern boundary of Atchafalaya Bay act to reduce the waves entering the bay from the open gulf and to alter current flow through and over the reefs.

38. Wave action is more significant in the Gulf of Mexico seaward of the Point Au Fer Shell Reef than in Atchafalaya Bay. Under normal conditions wave heights range from 2 to 4 ft, and 95 percent of the time waves do not exceed 4 ft (Cratsley, 1975). Short-period swell with periods of 4 to 8 sec is common. A majority of the swell arrives from the south because of refraction over the shallow bottom. The broad and smooth shallow sea floor off Atchafalaya Bay causes waves approaching from the offshore area to be modified in height by refraction and frictional dissipation.

39. Longshore currents on the open coasts flow from east to west throughout the year due to the predominantly onshore winds from southeasterly directions. Coastal currents in the offshore area gulfward of Eugene Island generally have velocities from 0.5 fps to 1.5 fps, with resultant directions of flow governed by the tidal stage and wind action (Garrett et al., 1969). This westerly flowing current moves the Atchafalaya River discharge westward, thus affecting the source salinity of the gulf end of Southwest Pass. Analysis of aerial photographs, taken over the last 20 years, suggests that sediments, in a seaward-moving suspended plume, move westward with the longshore drift (Shlemon, 1975).

Tides

40. The tide in this region of the Gulf of Mexico is mixed diurnal based on a comparison of the relative magnitudes of the principal daily (K_1 and O_1) and semidaily (M_2 and S_2) harmonic constituents. Mixed diurnal is a classification that indicates tides in this area are between being infrequently diurnal to predominantly diurnal. Tidal elevations for the period 1942 to 1967 expressed in feet referred to NGVD at Morgan City, Calumet, and Eugene Island are:

	Ranges and Elevations, ft*		
	Morgan City	Calumet	Eugene Island
Extreme spring tide range	3.9	3.8	-
Mean diurnal tide range	1.3	1.4	1.9
Mean high water	1.9	1.9	-
Mean low water	0.75	0.84	-
Effects of hurricanes (maximum high water)	8.5	8.3	6.8
Effects of northerly storms (maximum low water)	-2.3	-2.8	-3.5

* Elevation refers to NGVD (data from Garrett et al., 1969)

41. Wind tides have a larger range with greater water level changes and last generally a week or longer compared with the diurnal nature of the tides. The tidal prism associated with the mean diurnal range of periodic tides of 1.5 ft in Atchafalaya Bay amounts to 25 percent of the volume of the bay contained below the mean water level. With a maximum diurnal range of 2.7 ft, the tidal prism amounts to 45 percent of the volume of the bay,and with a semidiurnal spring range of 2.5 ft, the tidal prism is 40 percent (Thompson, 1955).

42. Tidal currents in the bay range from 1 to 2 fps depending on the phase of the tidal cycle and wind action in the bay. Generally, during the flooding period of the tidal cycle, the current of the Atchafalaya River is directed toward the southeast in the navigation channel; and during ebbing, flow is to the southwest. Average tidal-current velocities over the Point Au Fer Shell Reef are 1.2 to 1.5 fps during ebbing tide and 0.7 to 0.8 fps during flooding tide (Thompson, 1955).

43. Tide data from Eugene Island indicate that in the last 30 years there has been an apparent rise in sea level averaging 1.3 cm/yr which is primarily a result of regional and local subsidence. Subsidence is due primarily to the compaction of clays by new deltaic deposits or to loading by the weight of the water column (Hicks 1973).

Sediment Characteristics

44. Sediment presently passing into the Atchafalaya Bay is coarser and contains a higher percentage of silt and very fine sand than in previous years. The present condition is a result of the changing dominance from silt

and clay during approximately 20 years. During the moderately high floods in 1968 and 1969, there was minimal response of sand transport. However, during the high floods in 1973, 1974, and 1975, a greater amount of sand was transported. Some have attributed this increase in sand-size sediment to the scouring of sand-size bed material in the lower basin and Lower Atchafalaya River and transportation as suspended load to Atchafalaya Bay during the extreme high-water events (Roberts et al., 1978).

45. During the high-water period of the early 1970's, both the volume and size distribution of sediments reaching Atchafalaya Bay via Lower Atchafalaya River changed significantly. Prior to this event, a regular sampling program in the Lower Atchafalaya River indicated an average annual sediment load of 47×10^6 tons for the period 1965-1971 (USACOE, 1974). The annual suspended sediment load during the three high-water years (1973-1975) nearly doubled, with the Atchafalaya River carrying 98×10^6 tons. Since Wax Lake Outlet carries about 30 percent of the total Atchafalaya River flow, it would be necessary to multiply the above values by 0.43 to get the approximate sediment discharges which would be associated with it. Roberts et al. (1978) indicate that during high-water periods 90 percent of the suspended load is sand, whereas during low flow this figure reduces to 25 percent. This again is verified by the fact that 37.5×10^6 tons of sand-size material introduced at Simmesport during 1973-1975 represents a twofold increase over the earlier period, while the 33.8×10^6 tons introduced into Atchafalaya Bay through Lower Atchafalaya River and Wax Lake Outlet during 1973-1975 represents a sevenfold increase (Roberts et al., 1978). Figure 5 is a plot of the average monthly flow and suspended sediment transport through the outlets during the period 1965-1967.

46. There have been three bed material surveys from which there is sufficient information to analyze. Data were collected in 1972 (477 samples) and 1975 (160 samples) by LMN. The Louisiana Wildlife and Fisheries Commission (LWLFC) collected data in 1972 (43 samples). Presentation of the data by Roberts et al. (1978), in which comparison of 1972 (LWLFC) and 1975 (LMN) data was made, shows a distinct shift from a dominance of the silty clays characteristic of distal bar deposits to the silts and sand silts characteristic of distributary mouth bar deposits laid down immediately prior to the subaerial stage of delta development. Histogram plots of the median grain-size distribution data show that there has been a substantial change in this sediment

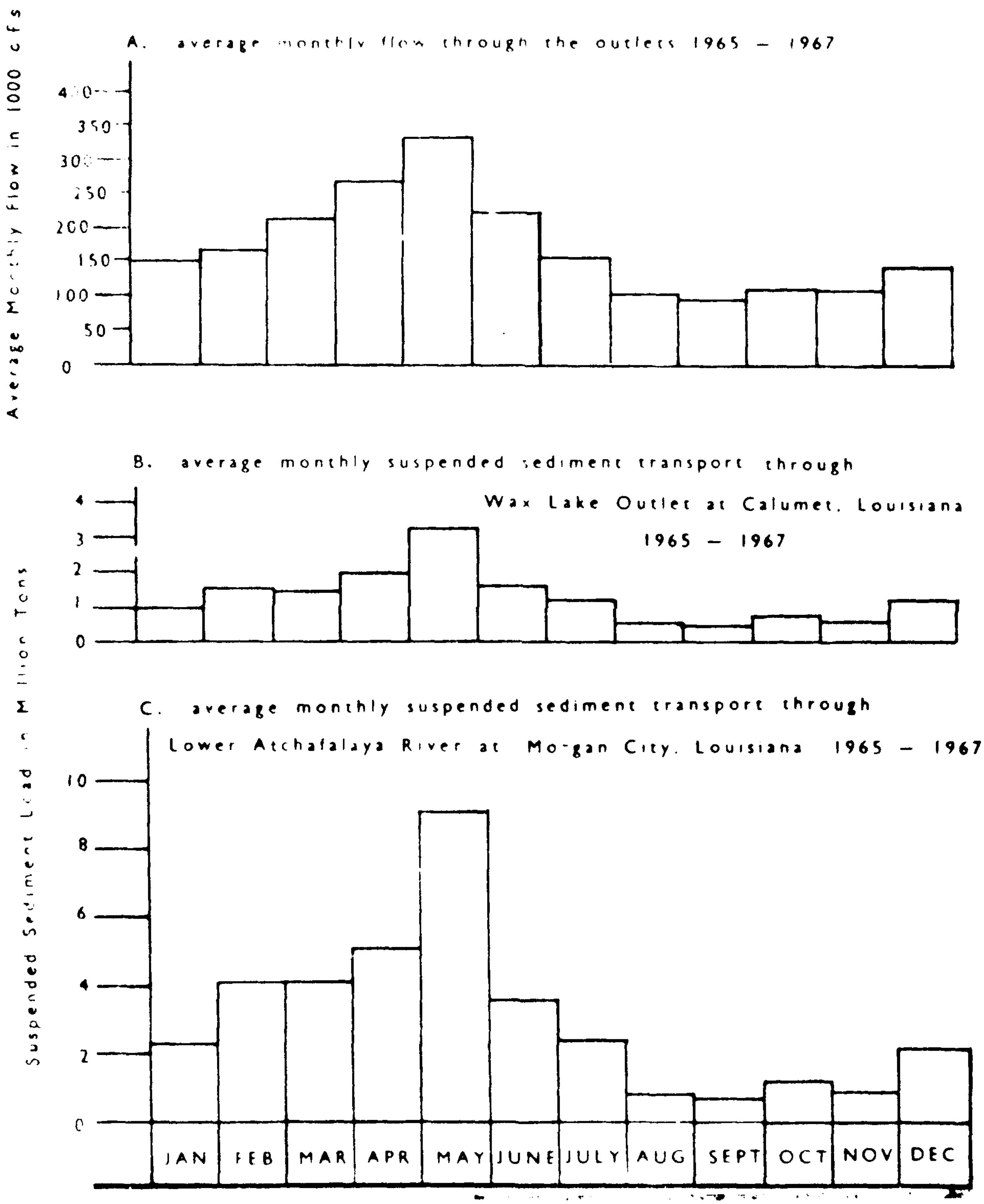

Figure 5. Average monthly flow and sediment discharge (from Cratsley, 1975)

characteristic from 1972 to 1975. In 1972, the median grain size showed a predominance of medium silt (0.0156 to 0.0313 mm) of 48.4 percent with some coarse silt (0.0313 to 0.0625 mm), 31.8 percent. The 1975 data show a decrease in medium silt (0.0156 to 0.0313 mm) of 34.0 percent with an increase in coarse silt (0.0313 to 0.0625 mm) of 47.5 percent. There is also approximately 10.5 percent of very fine sand (0.0625 to 0.125 mm).

47. Another means to analyze bed material data is to use statistical comparison techniques. In this study, a combination of two multivariate analyses were used--cluster and factor analyses. These two analyses procedures were run using the Statistical Analysis Systems (SAS) programs. The 1975 bed material data (159 samples) were used with the parameters of median grain size and percent silt and clay specified. Ten clusters were specified for analysis. Generally, the procedure grouped data in clusters that showed decreasing percent silt and increasing median grain size. The cluster group with the largest number of samples contained a high percentage of silt (mean, 81.3 percent) and a small median grain size (0.03052 mm) and was in the western portion of Atchafalaya Bay and along the Point Au Fer Shell Reef. The cluster groups with the highest mean median grain size and lower percent clay are associated with those stations closest to the two outlets.

48. During the months of July through October 1976, Coastal Environments, Inc., obtained a total of 120 sediment cores along a series of transverses (Gagliano et al., 1977). The cores were 2-1/2 in. in diameter and contained the upper 2 to 3 ft of bottom sediments. The cores were cut lengthwise; logged for sediment type, color and sedimentary structures; and then photographed. A selected number of cores were X-rayed to better visualize sedimentary structure as a basis for determining the mode of deposition. Additionally, a number of samples were submitted to X-ray diffraction to determine the percentage occurrence of certain clay types to evaluate possible sources of sediment.

49. Gagliano et al. (1977) summarized the results of their core study by saying: "The core analyses suggested that deposition of clays and silty clays increase westward from East Cote Blanche to Vermilion Bay in accordance with the suggested controls of water chemistry and protection from wave action. It shows a sediment sorting process related to the physicochemical variation of the bay complex which enhanced deposition of clays in Atchafalaya Bay and East Cote Blanche Bay only as long as depth and mixing with marine

water were sufficient. With a decrease in both these elements, deposition in Atchafalaya Bay is shifted to silty sediments, and clays become increasingly available for transport beyond the bay into the Gulf of Mexico and the Cote Blanche and Vermilion Bays."

Water Quality

50. The average salinity of the bay system varies for the most part on a seasonal basis and is inverse to the Atchafalaya River discharge, reaching a maximum at the time of minimum flow from the Atchafalaya and a minimum at the time of maximum flow. The effects of local runoff from the minor tributaries may reverse the seasonal trend for short periods of time in certain portions of the bay system, but such effects appear to be insignificant in both extent and duration as compared with the seasonal trend. There have been occasions when salinities throughout the system have been reduced essentially to zero as a result of sustained high discharge from the Atchafalaya River. Maximum salinities on the order of 6 to 8 parts per thousand (ppt) have been measured along the west and north sides of Vermilion Bay near the end of a period of sustained low Atchafalaya discharge.

51. After a period of high freshwater discharge which has essentially freshened the entire bay system, the return of saline water into the systems appears to follow a fairly well-defined pattern. The initial intrusion occurs through Southwest Pass into Vermilion Bay; then the salt water fans out through Vermilion Bay and into West Cote Blanche Bay. By the time the salt-water front has reached the central portion of East Cote Blanche Bay, the Atchafalaya River discharge has usually decreased to such an extent that the salt water from the gulf begins to intrude into the western portion of Atchafalaya Bay. Salt water from this source apparently meets that intruding from Southwest Pass in the vicinity of Marone Pt. This pattern is capable of considerable variation, however, depending on local runoff into Vermilion Bay.

52. An inventory and study of the Atchafalaya-Vermilion complex by LWLFC were conducted between April 1972 and March 1974 and were reported by Juneau et al. (1975). Seventeen salinity stations located throughout the estuary were monitored every 3 to 5 days throughout the period. Samples were collected at the surface and near the bottom. At each station the two salinity readings were very similar and were most often identical. Salinities were

highest at the westernmost stations and lowest at stations located in the eastern portion of the study area. Lowest salinity average for the study period was 0.3 ppt, recorded at Point Chevreuil and GIWW at Wax Lake Outlet. Freshwater Bayou had the highest average annual salinity with a 9.7 ppt recording, and Southwest Pass was fairly high with an annual average of 6.1 ppt. Highest salinity averages for all stations combined were recorded during July and August with an average of 6.2 ppt and 5.8 ppt, respectively. Lowest salinities were during April and May, both with an average of 1.2 ppt. These months coincide with high river discharges. The average annual salinity for all stations combined with 2.9 ppt. It should be noted, however, that overall salinities could have higher averages during normal years, since 1973 was a flood year.

53. Salinity measurements were made by LMN on a biweekly basis at 30 coastal locations in the region influenced by the Atchafalaya River discharge. These stations are part of a water quality monitoring network established in 1973 and subsequently sampled through 1977. These samples were collected at the surface, and seven of the stations were in the immediate vicinity of the Atchafalaya-Vermilion complex. These data, when averaged monthly over the 4-year sampling period, show much less influence of Atchafalaya River discharge when compared with LWLFC data, especially in the winter-spring period. Discrepancies between the two studies appear to have resulted from the periods sampled. The LWLFC study covered the flood years of 1973-1974 and the Corps study included the flood years plus the dry years of 1976-1977. The Corps study represents a more typical period of record and is thought to be a more reliable indication of average salinity conditions (Cunningham, 1978)

54. Temperatures recorded during LWLFC data collection followed similar trends compared with salinities. Water temperatures were generally higher on the western edge of the study area compared with the eastern stations. Average water temperatures for all stations combined were lowest during December with a reading of 11.7°C. Water temperatures were also quite low during January, February, and March. Warmest water-temperature months were July and August with 29.5°C and 29.3°C readings, respectively (Juneau et al., 1975). The average annual water temperature for all stations combined was 21.2°C. During the LWLFC study, collected water samples were also analyzed for dissolved oxygen, nitrate, nitrite, inorganic phosphates, and total phosphorus.

Navigation and Flood-Control Projects

55. The main navigational channel bisects Atchafalaya Bay, extending from the mouth of the river through the Point Au Fer Shell Reef at Eugene Island and thence to the 20-ft contour. The initial project was authorized by the River and Harbor Act of 25 June 1910 to provide a 20- by 200-ft navigation channel from the mouth of the Atchafalaya River to the 20-ft contour in the gulf. The channel, completed 14 October 1911, is presently 20 by 400 ft and was authorized by the River and Harbor Act of 13 August 1968. The River and Harbor Act of 28 June 1938 authorized Wax Lake Outlet, a floodway channel 45 by 300 ft at its head in Six Mile Lake increasing to 400 ft at its mouth in Atchafalaya Bay. The outlet, designed to handle a maximum capacity of 275,000 cfs, was completed in 1942. From Wax Lake Outlet, a 4-mile-long channel trends southward from New Pass to an inner reef shoal area. Dredging to maintain the navigation channel has left several submarine disposal banks parallel to the main cut. Although small in volume compared with natural sedimentation, some dredged material has been incorporated into the expanding Atchafalaya delta.

56. Heavy dredging was required in the bay navigation channel during the high discharge years of 1973-1975. During the period 15 May to 30 June 1973, approximately 1.6 million cubic yards was dredged. From 1 July 1973 to 21 November 1973, 5.2 million cubic yards was dredged, and this decreased to 2.6 million cubic yards during the period 20 January 1974 to 10 April 1974. Therefore, during the two-year period from 15 May 1973 to 30 June 1975, approximately 9.4 million cubic yards was dredged. In a low discharge year, little or no dredging is normally required in the bay channel.

57. Fisk, commenting on the paper by Thompson (1955), said that he felt this dredged channel exerts control on sedimentation by directing the flow of the river; therefore, in a sense, the dredged channel determines the site of deposition and the quantity of the Atchafalaya River sediment which reaches the gulf.

58. The Atchafalaya Basin Floodway, authorized in 1928, was formed by construction of the east and west Atchafalaya Basin protection levees. This levee system is generally parallel to the Atchafalaya River. The east Atchafalaya Basin protection levee begins at the lower end of the lower guide levee of the Morganza Floodway and extends southward to Cutoff Bayou about

12 miles below Morgan City. The levee system is 88.67 miles, including 1.3 miles of floodwall at Morgan City and 0.4 mile of floodwall below Morgan City. It includes Bayous Sorrel and Boeuf Locks.

59. The west Atchafalaya Basin protection levee begins at its junction with the Bayou des Glaises fuseplug levee near the town of Hamburg and extends in a southerly direction to the Wax Lake Outlet. It continues eastward to and through Berwick to the GIWW. It includes 1.0 mile of floodwall to the north of Berwick. This levee is approximately 149.1 miles in length. It contains the Bayou Courtableau Drainage Structure, the Bayou Darbonne Drainage Structure, the Charenton floodgate, the Berwick lock, and the east and west Calumet floodgates. Also associated with this levee is the Bayou des Glaises Diversion Channel completed in 1939.

PART III: SOLUTION REQUIREMENTS AND METHODS

60. The Corps of Engineers' responsibilities in the Atchafalaya Basin and Bay system require that the questions listed in the Introduction of this report be answered in sufficient detail to clearly show differences in effects of several alternative courses of action. The answers must also be reliable enough to justify their use as major considerations in decisions affecting preservation and management of the Atchafalaya's physical and biological environments and expenditure of large sums of Federal and private funds. Practical constraints add the requirements that these answers be obtained in a timely, cost-effective manner. This portion of the report examines the requirements that a proposed solution plan must satisfy in order to meet the Corps' responsibilities

Solution Requirements

Area of interest

61. The area of primary interest is shown in Figure 6--Atchafalaya, Fourleague, East Cote Blanche, West Cote Blanche, and Vermilion Bays; a portion of the Gulf of Mexico; Wax Lake Outlet and the lower Atchafalaya River to a point above Morgan City; and a portion of the GIWW. This area covers more than 2000 square miles.

62. The upstream and gulfward limits of the area of interest to this investigation are as shown in Figure 6, but in order to properly pose boundary conditions, areas beyond these limits must be included in the analyses.

Predicting delta growth

63. A fairly simple representation of the Atchafalaya system can be used to predict gross features of delta development such as areal extent or deposition volume. For example, a sediment budget analysis using recent bathymetric and sediment discharge measurements can be related to rates of bay filling and used to extrapolate into the future for the case of no modifications to the system However, this simple technique provides little information on events in the adjacent bays and it becomes less reliable as the period of extrapolation becomes longer. For an alternative such as some structural modification or diversion, such a simplified approach is much less accurate than for existing conditions. If details of flow, water quality, and

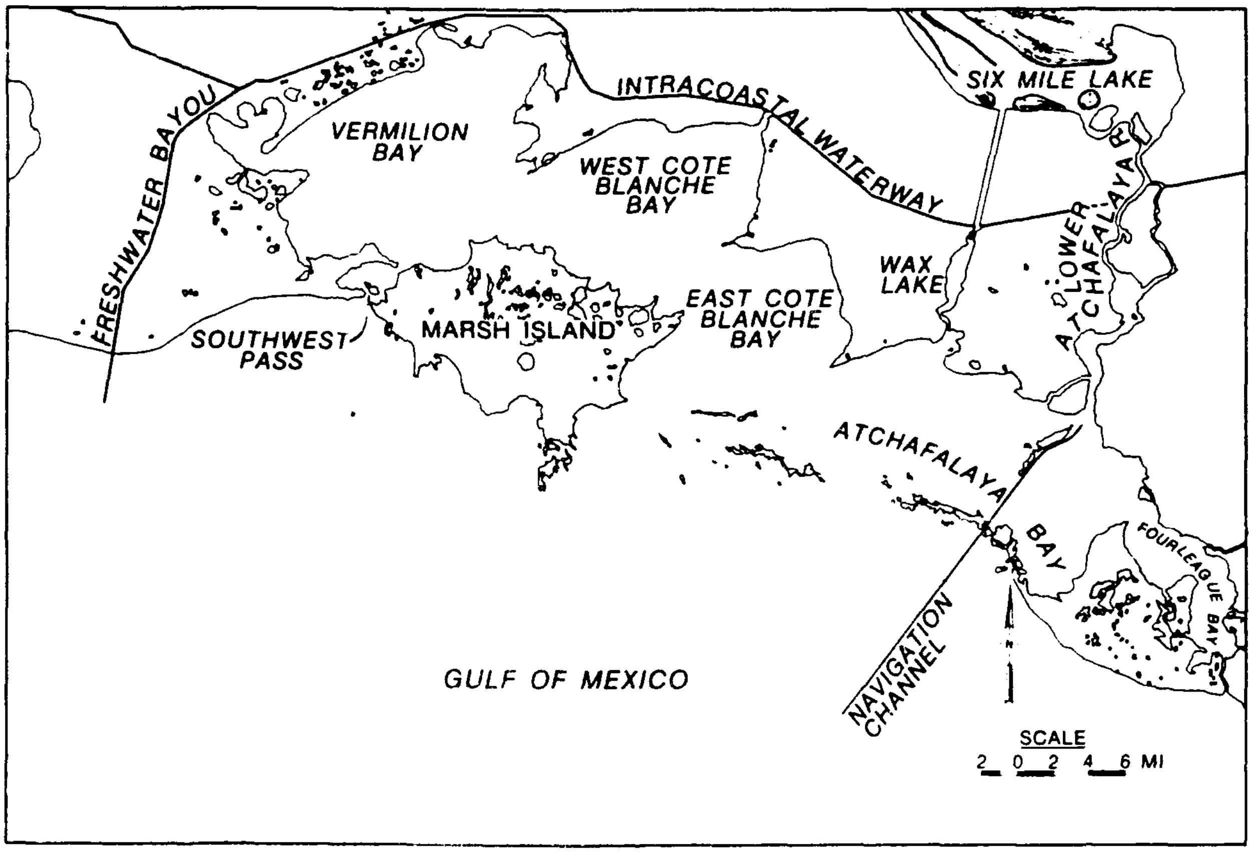

Figure 6. Location map of the Atchafalaya Bay area

delta development, predictions for Vermilion Bay and the intervening areas, or reliable predictions of alternative courses of action are needed, more rigorous methods must be considered.

64. Accurate modeling of delta growth requires that sedimentation processes (erosion, transport, deposition, and consolidation) be reproduced for each class of sediment involved. Sands, silts and clays appear in the area in sufficient quantities to require their inclusion in the modeling efforts. Modeling sedimentation processes requires that sediment sources be identified as to quantity and character, and that the primary transporting mechanisms be described. Specifically, modeling of sedimentation in Atchafalaya Bay requires prediction of sediment supply plus water-surface elevations and currents due to some or all of:

a. River discharge.

b. Tidal currents.

c. Short-period waves.

d. Wind-induced currents.

e. Storm surges.

f. Density currents.

g. Turbidity currents.

These are listed in descending order of apparent importance to the Atchafalaya delta. The sequence will probably change for other locations in the system, and the exact order of importance is subject to some debate. Perhaps some of the items may be deleted without serious impact on the results.

65. To model the hydrodynamic conditions listed above, it is necessary to adequately predict boundary conditions of:

a. River stage and discharge.

b. Gulf tides.

c. Coastal currents.

d. Storm surge gulf elevations.

e. Winds.

and initial conditions of bathymetry and bed character. These must be supplied at properly posed boundaries at time scales required by the hydrodynamic modeling.

66. Boundaries must be located so that conditions there are readily defined and so that the boundaries' presence does not influence results in the area of interest. Boundaries must be sufficiently remote that potential

system alterations to be tested do not change the boundary conditions; yet they should not be so far from the area of interest as to unnecessarily increase study costs.

Predicting flood stages and flow distribution

67. Prediction of flood stages and flow distribution among outlets requires much of the same hydrodynamic input as that for sedimentation. Gulfward and upstream water surface elevations and flows must be known, and the flow resistance of the growing delta and outlets must be quantified.

Predicting salinity

68. To predict salinity conditions, the same hydrodynamic information is required as listed in paragraph 64. In addition, dispersion due to spatial and temporal resolution of hydrodynamics must be quantified.

Required resolution

69. Requirements for spatial resolution of details vary with the problem being addressed. For example, evaluation of habitat changes requires that bay infilling and salinity changes be resolved on a horizontal spatial scale of acres to square miles, whereas navigation channel shoaling predictions must be based on areal analyses of no more than a few hundred square yards. Likewise, evaluation of scour in outlets to the bay requires resolution of features a few hundred yards or less across Vertical scale resolution required for all phenomena is at least in feet, perhaps fractions of a foot.

70. Most of the processes to be considered can be adequately addressed by a two-dimensional (plan form) treatment that integrates over depth.

71. Time resolution requirements, like those of space, vary among the questions to be answered. Sedimentation results need to be examined in time periods as short as several months or as long as decades. Such a large range of time needs almost certainly requires more than one approach. A solution method that can satisfactorily predict details occurring in a few months will be unwieldy in predictions of several decades duration. Salinity changes on the order of weeks may be important, but months are a more likely time frame. In contrast to all of these, flood stages require daily and sometimes even hourly predictions.

Flexibility

72. Because of an unusually long expected period of operation for the Atchafalaya investigation, a basic requirement is flexibility--an ability to

modify the plan in future years without beginning anew. Solution method systems used in coastal engineering have evolved rapidly in recent years and will continue to evolve during the life of this investigation. Therefore, it is imperative that the Atchafalaya plan be able to evolve by incorporating new techniques as they are developed.

Solution Methods

73. Solutions to coastal hydraulics problems are obtained principally by use of the four primary methods--field investigations, analytical solutions, numerical models, and physical models. Any of these four may be the best single approach for solving a particular problem. Choosing among them requires knowledge of the phenomena that are important to the problem, an understanding of the strengths and weaknesses of the solution methods, and evaluation of the resources available for the study in comparison to the need for accurate results.

Field investigations

74. Field (prototype) data collection and analysis serve both as an important aspect of the other solution methods and as an independent method. Alone, field data show the estuary as it behaved under a certain set of conditions prior to and at the time of measurement. By skillful scheduling of data collection and careful analysis, one can obtain estimates of the separate effects of tides, river discharge, wind, etc. Field data can reveal problem areas and define the magnitude of problems and can, to a limited extent, be used to estimate the estuary's response to different conditions of tide and river discharge. Accurate field data are indispensable elements of correct verification of numerical and physical models.

75. Obtaining sufficient temporal and spatial data coverage in the field is a formidable and expensive task; therefore, available field data are often too sparse to describe an estuary in any but the most general terms. Analysis of field data cannot provide reliable estimates of the estuary's response after proposed modifications to the estuary. Those not closely familiar with the science of data collection and analysis often overestimate its accuracy and reliability. Use of data without a thorough understanding of its limitations can lead to serious error.

Analytical solution methods

76. Analytical solutions are those in which answers are obtained by use of mathematical expressions, or equations, which describe physical phenomena in mathematical terms Thus, they may be considered to be mathematical models of physical reality. For example, Manning's equation is a simple analytical model of the complex process of energy losses in open channel flows. A more rigorous and complete analytical model of the losses is included in the Reynolds form of the Navier-Stokes equations.

77. Mathematical, or analytical, models usually combine complex, poorly understood phenomena into coefficients which are determined empirically. Manning's roughness coefficient, for instance, combines the various effects of energy dissipation into a single parameter. The degree of simplification of the analytical model dictates how it is solved. For example, Manning's equation can be solved directly, whereas the more elaborate Navier-Stokes equations must be simplified and solved by numerical methods.

78. If an analytical model can be solved by substituting values of the independent variables into the equation (a closed form solution), then the solution method is also analytical. The calculation may be performed by hand or by a computer, but the solution is still an analytical one.

79. The analytical solution method has advantages of speed and simplicity but it cannot provide many details. In estuaries, analytical solutions can be used for gross representations of tidal propagation and average cross-sectional velocities in simple geometries. Details of flow cannot be predicted. The usefulness of analytical solutions declines with increasing complexity of geometry or increasing detail of results desired.

Numerical modeling

80. Numerical modeling is a relatively new technique (compared to the other three) that employs special computational methods such as iteration and approximation to solve mathematical expressions that do not have closed form solutions. A numerical model thus applies numerical (computational) analysis to solve mathematical expressions that describe the physical phenomena.

81. Numerical models used in coastal hydraulics problems are of two principal types--finite difference and finite element. The finite difference method (FDM) approximates derivatives by differences in the value of variables over finite intervals of space or time. This requires discretization of space and time into regular grids of computation points. Finite difference methods

have been in widespread use for unsteady flow problems for a number of years. The finite element method (FEM) has more recently begun to be applied to hydrodynamic problems. This method employs piecewise approximations of mathematical expressions over a number of discrete elements. The assemblage of piecewise approximations is solved as a set of simultaneous equations to provide results at points in space and time.

82. Numerical models are classified by the number of spatial dimensions over which variables are permitted to change. Thus in a one-dimensional flow model, currents are averaged over two dimensions (usually width and depth) and vary only in one direction (usually longitudinally). Two-dimensional models average variables over one spatial dimension, either over depth (a horizontal model) or width (a vertical model).

83. Numerical modeling provides much more detailed results than analytical methods and may be substantially more accurate, but it does so at the expense of time and money. Once a numerical model has been formulated and verified for a given area it can quickly provide results for different conditions. In addition, numerical models are capable of simulating some processes that cannot be handled in any other way. However, present models are limited by the number of dimensions and degree of resolution that are practical on available computers. They are also limited by the modeler's ability to derive and accurately solve mathematical expressions that truly represent the physical processes being modeled.

Physical models

84. Physical scale models have been used for many years to solve coastal hydraulics problems. Careful observance of appropriate scaling requirements permits the physical modeler to obtain reliable solutions to problems that often can be solved no other way. Physical hydraulic models of estuaries can reproduce tides and other long waves, some aspects of short-period windwaves, longshore currents, freshwater flows, pollutant discharges, some aspects of sedimentation, and three-dimensional variations in currents, salinity, density, and pollutant concentration. Present practice does not include simulation of water-surface setup and currents due to wind. Applicability of model laws and choice of model scales are dependent on which of these phenomena are of interest. Conflicts in similitude requirements for the various phenomena usually force the modeler to forgo similitude of some phenomena in order to more accurately reproduce the dominant processes of the

situation. For example, correct modeling of tides and currents often requires that a model have different scales for vertical and horizontal lengths. This geometric distortion permits accurate reproduction of estuarine flows and is a common and acceptable practice; but it does not permit optimum modeling of short-period waves, which requires an undistorted model for simultaneous reproduction of refraction and diffraction.

The hybrid method

85. The preceding paragraphs have described the four principal solution methods and some of their advantages and disadvantages. In practice, two or more methods are used jointly, with each method being applied to that portion of the problem for which it is best suited. For example, field data are usually used to define the most important processes and to verify a model that predicts hydrodynamic conditions in an estuary. Combining two or more methods in simple ways has been common practice for many years. Combining physical modeling and numerical modeling to provide results not possible any other way is termed a hybrid modeling method. Combining them in a closely coupled fashion that permits feedback among the models is termed an integrated hybrid solution (McAnally, et al 1984).

86. Judicious selection of solution methods in a hybrid approach can greatly improve accuracy and detail of the results. By devising means to combine results from several methods, the modeler can include effects of many phenomena that would be neglected or poorly modeled by a single approach. For example, as described earlier, physical model scaling requirements for tidal flows and short-period waves conflict, and both are included in models only at the expense of imprecise modeling of one or the other. By modeling them separately and integrating the results, the modeler can predict both to the best of his modeling capability. Thus, the hybrid approach exploits strengths of each solution method while avoiding weaknesses.

PART IV: THE PLAN

Approach

87. The plan called for adaptation of a number of numerical models and analytical methods plus revision of the Atchafalaya portion of the existing WES fixed-bed physical model of the Mississippi Basin (MBM). These were used in an integrated solution method that used the strong points of each technique to maximum effect.

88. After short- and long-term delta growth predictions were made for the do-nothing alternative, the same procedures were used to determine the effect of various alternatives. Predictions were made using approximate or specified structure effects (head loss, etc.), but structure design was not included in this plan.

89. The original plan, described in the following paragraphs, was comprehensive in that it provided for prediction of all the processes described in paragraphs 64 and 65. This completeness was not intended to suggest that it was practical or necessary to answer the significant questions about the Atchafalaya system. For this reason, the implementation schedule provided that the most important processes were dealt with first, and the other processes were examined carefully before eliminating them or incorporating their prediction into the plan. The plan included five techniques for predicting delta growth- extrapolation of past behavior, generic analysis (comparison with other deltas) analytic calculations, quasi-two-dimensional modeling, and fully two-dimensional modeling. Five separate techniques were used because the possibility for error was quite high, given the long period to be predicted and the dramatic changes in physical environment that were expected. A multiple path approach provided results early and at regular intervals throughout the investigation and provided internal checks to narrow the confidence limits about the final results.

90. The plan used modular components for modeling various aspects of the problems. This provided flexibility to incorporate new or superior techniques with minimum disruption and permitted efficient modeling by separation of some phenomena to reduce computation effort. The major example of separation is division of hydrodynamic and sediment transport modeling into loosely coupled, separate operations. More efficient modeling occurred because time

steps were tailored to fewer processes, and sediment transport computations used smaller time steps than hydrodynamic computations. Additional savings were created by using hydrodynamic results in repetitive fashion and redefining hydrodynamics only when and where required by bathymetric change. Also, subsequent experience with the recommended methods led to changes in the plan. The plan's modular construction was intended to facilitate these changes when needed.

91. In selecting solution methods, an attempt was made to balance the plan's component operations such that precision and accuracy were of about the same order among the components. This goal was not attainable in some cases because of specific plan needs, relative importance of the particular phenomena, and ability to use the results produced.

92. Solution methods used in the plan were existing methods; however, developmental work was required on some of the methods. Efforts to adapt models for proper application to the Atchafalaya are briefly described in the following paragraphs.

93. During early stages of this work, a rigorous search of the literature was made to locate pertinent data relating to Atchafalaya Bay system physical processes. The resulting bibliography was organized and indexed for use by personnel working on the project. During the execution phases, items were added to the bibliography when they came to the attention of project staff, but no special effort was made to update the bibliography. The bibliography is included with this report as Appendix A.

Data Management

94. First on the list of recommendations was the application of the WES data management system to the Atchafalaya Bay system. This collection of data management tools has been developed over a number of years by Dr. Victor LaGarde and his associates in the WES Environmental Laboratory (previously Mobility and Environmental Systems Laboratory). It consists of a group of computer programs which, in combination with consistent data storage methods, permit rapid accession, manipulation, analysis, and display of a variety of spatially and temporally distributed data. This versatile system has been adopted for use in this effort after a review of the capabilities of several such systems. Initial applications to the Atchafalaya have already been made

to contour and compare hydrographic surveys and to contour bed material data. The data management system referred to in the following pages is the WES-LaGarde system.

95. Using this data management system, LMN personnel were able to remotely access data files for manipulation, analysis, and display. This represents a substantial improvement in the way that modeling results are presented in that district personnel can create their own data displays.

Organization of the Plan

96. Figure 7 shows the general organization of the plan for predicting delta growth with the five approaches. All required that, for a given condition such as the no action alternative, initial conditions of bay shorelines and bathymetry (hydrography) be specified. The 1977 condition was chosen as that initial condition. Each also required that boundary conditions of flow (and/or water level) and sediment supply be specified. With those conditions, each method was applied independently and sequentially to predict delta growth.

97. The *regression/extrapolation technique* (Letter, 1981) took existing data on river flows, sediment supply, and bathymetry and developed an equation relating deposition to river discharge, sediment discharge, and location in the bay.

98. The generic analysis (Wells et al., 1984) examined other deltas developing in similar circumstances to provide a characteristic growth cycle, then fit existing development of the Atchafalaya delta to that cycle and extended it for 50 years.

99. The analytic calculations method used an analytic solution of the plane jet equations to provide a geometrically simple delta development pattern. That pattern was repeated in a number of cycles with artificial bifurcation to generate a calculated 50 year delta. The analysis also showed the relationship between such parameters as outlet size and deposition pattern (Wang et al., 1985).

100. The quasi-2D modeling effort applied HAD-1, the strip version of HEC-6, to the lower basin. Longitudinal flow and sediment transport were calculated fully and lateral flow and sediment transport were solved in a

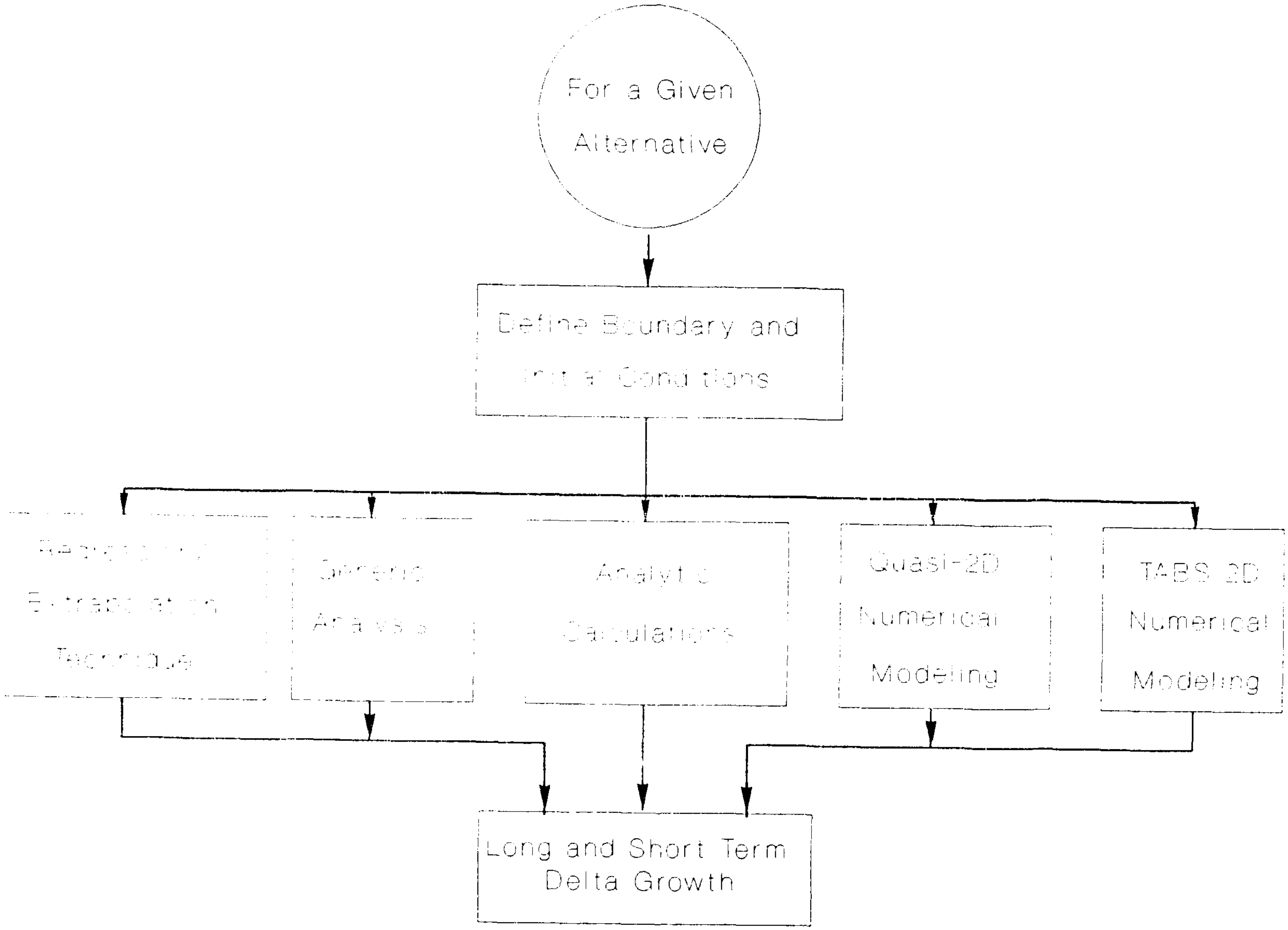

Figure 7. Methods for predicting delta growth

simplified manner (Thomas et al., 1988). It was run for a full 50-year continuous simulation.

101. The fully 2D modeling effort employed the TABS-2 numerical modeling system to make detailed predictions of flows, sedimentation, and salinity transport. Short, detailed runs were extrapolated in several cycles to obtain 50-year delta predictions (Donnell, Letter, and Teeter 1991).

102. For a given alternative (either no action or a possible modification to the Atchafalaya system) boundary conditions of flows, water-surface elevation, sediment supply, waves, and wind were determined at the boundaries of the area of interest. Next, initial conditions of bathymetry, bed character, and hydrodynamics were defined. Using these data, hydrodynamic and salinity conditions in the area of interest were predicted and then used to predict sediment transport and delta growth. The process was repeated for a variety of boundary conditions. Delta growth rates for each boundary and hydrodynamic condition were assembled by a statistical approach to predict short term delta growth. When predicted bed changes required, new initial conditions were defined and the prediction cycle was repeated. Long-term delta growth was predicted by accumulation of a series of short-term projections. At desired intervals, delta development and its effects were displayed for evaluation.

103. Figure 8 shows a general sequence of steps performed in the 2D modeling. Each of the steps consisted of a number of separate operations. The following paragraphs describe them in more detail.

Step 1: select the alternative

104. The initial alternative considered was no action, in which the delta was allowed to develop as it would with no efforts to alter that development other than those already employed, e.g., navigation channel maintenance. Subsequent alternatives to modify behavior of the system were examined either on a "what if?" basis or as a design procedure to establish guidelines for alternative performance. The results of base condition, (no action), projections were used for comparison with all subsequent plans (Donnell and Letter, 1991).

Step 2: define boundary conditions

105. Since the boundaries are far enough from the area of interest that changes within the area do not affect boundary conditions, they may be defined the same for any plan to be considered.

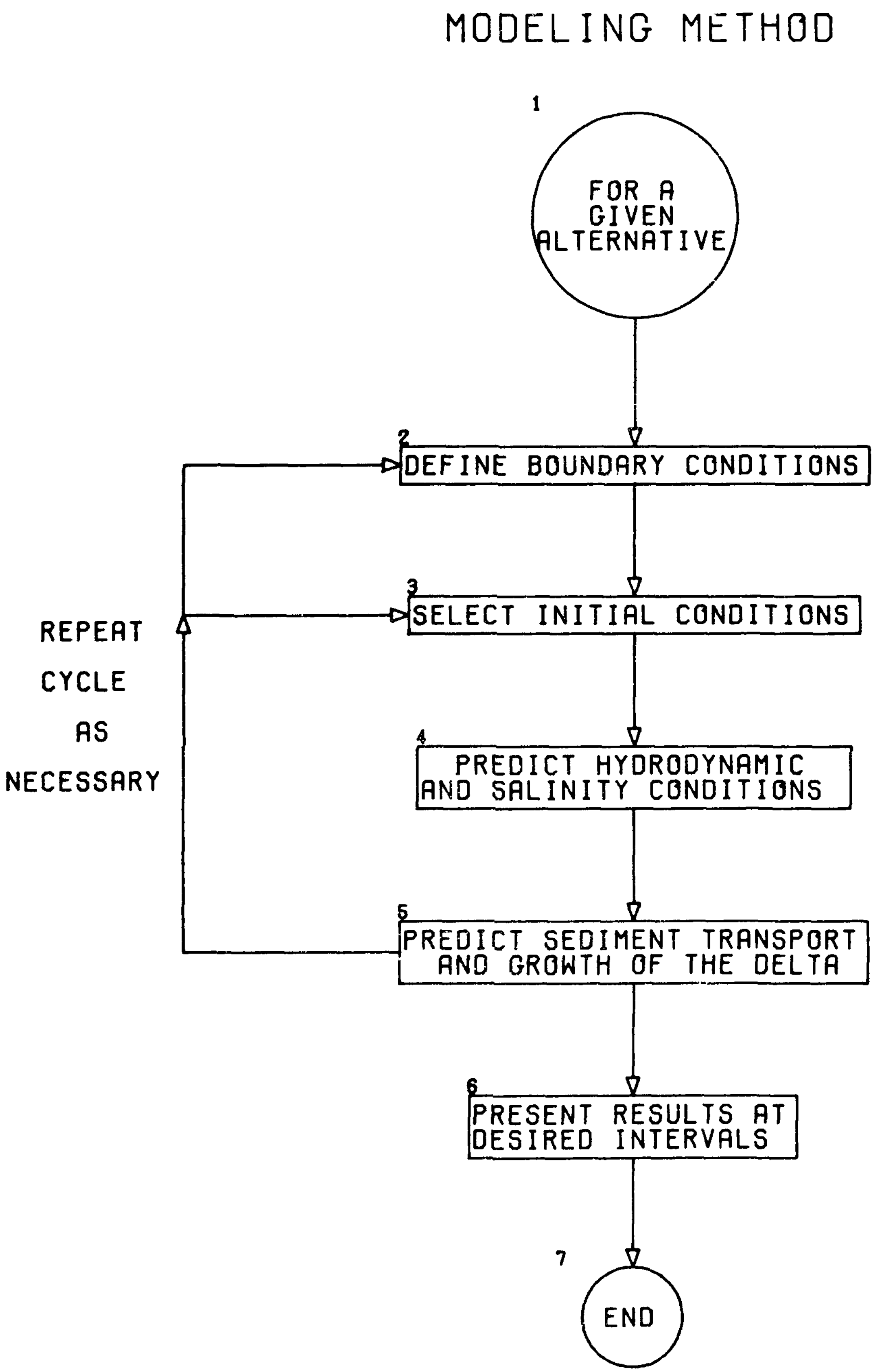

Figure 8. General organization of modeling steps in the plan

106. Since events such as floods and hurricanes occur randomly, their effects on boundary conditions must be treated statistically. Thus, representative boundary conditions were needed for normal variations such as wet, dry, and normal vears plus some extreme events.

107. The operations to define boundary conditions, shown in Figure 9, are described below. Numbers in the descriptive list refer to the same numbers near the upper left corner of the boxes in Figure 9.

a. 2-1. Wind. Winds over the area of interest, including tropical storms, and possibly nonstorm or daily winds were defined. Tropical storm wind fields for various storm tracks and strengths were described with a numerical model. Extratropical storm winds and nonstorm winds were defined by transforming historical wind data at nearby land stations and offshore stations using relationships developed between new wind measurements obtained at several stations over the area of interest. This latter procedure was initiated by the Center for Wetland Resources, Louisiana State University, as part of a separate but related investigation of Atchafalaya Bay (Jensen, 1985).

b. 2-2. Gulf Water Surface Elevation and Currents. Water-surface elevations and currents at the gulf boundary were defined by the following procedures:

(1) Astronomical tides were assembled by synthesis of harmonic constituents determined by analysis of field data, and model tides and tidal currents with a coarse-grid numerical hydrodynamic model of the Gulf of Mexico (Reid and Whitaker 1981).

(2) Seasonal variations in coastal currents were determined by analysis of field current measurements and LANDSAT imagery.

(3) Storm surges were reproduced by the two-dimensional numerical model WIFM. This and other Corps of Engineers' modeling efforts in the Gulf of Mexico justified a jointly sponsored coarse-grid numerical model of gulf hydrodynamics used in these predictions.

c. 2-3. River Flows and Stages.

(1) Representative stages and discharges at Simmesport, Louisiana, were defined by analysis of available historical data. These flows were routed to the lower basin by the dynamic, branching one-dimensional numerical model SOCHMJ and the existing MBM (USAEWES, 1973).

(2) The MBM was modified to include the bay and gulf areas shown in Figure 6, and the numerical model extended to the same area. Thus, these computations overlapped hydrodynamic modeling of the bays in Step 4 and permitted correct specification of an upstream boundary condition for

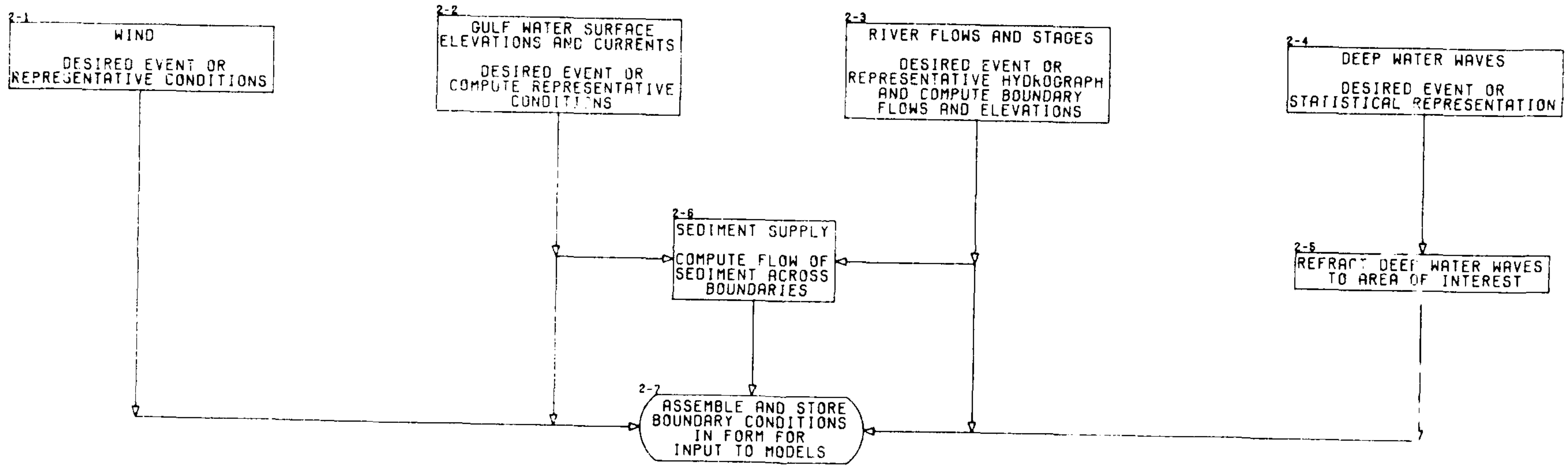

Figure 9. Operations to define boundary conditions

the bay models at a convenient point rather than beyond the influence of bay events. Routing of flows from Simmesport to the basin was then both a boundary condition computation and a hydrodynamic result computation.

d. 2-4. Deepwater waves. Existing hindcast statistics (Beach Erosion Board, 1956), SSMO data (U. S. Naval Weather Service Command, 1975), and data collected at offshore drilling sites were used in the early stages of the study.

e. 2-5. Refraction of Deepwater Waves. If deepwater waves were shown to experience refraction and shoaling gulfward of the boundary, wave transformations were developed by use of an available refraction model (Jensen, 1985).

f. 2-6. Sediment Supply. Sediment supply rates and character were defined by the following procedures: Sediment supply from the Atchafalaya River were determined by analysis of measurements at Simmesport, Louisiana. Representative sediment loads were routed to the upstream boundary by use of HAD-1, the quasi-two-dimensional, strip version of numerical model HEC-6 (Thomas et al. 1988).

g. 2-7. Assemble and Store Boundary Conditions. Boundary condition data were collected from the several operations and the data management system used to combine and order them, with sets of conditions written to data files for use by subsequent modeling efforts.

Step 3: selection of initial conditions

108. Initial conditions to be used were specified and the data management system used to select bed elevations, bed character, sediment concentration distribution, water-surface elevations, current velocities, salinity, and wave spectra over the area of interest at the beginning of the computation cycle. Since the cycle was repeated, ending conditions for one computational pass served as initial conditions of the next pass. Manipulation of data by the management system included acquiring the data and writing them to files required by subsequent computations plus possible interpolation in space and time.

109. Initial conditions for predictions of delta growth with no effort to modify the system started with recently observed bathymetry. Testing of possible modifications to the Atchafalaya system started with predicted bathymetry at the time the modification could reasonably be expected to be made.

Step 4. defining hydrodynamics

110. Hydrodynamic conditions were defined for a variety of representative and extreme boundary conditions. Then, depending on how they were to be

used, they were sequenced and combined to represent a satisfactory time history to be used in sediment and water quality computations. Methods used are illustrated in Figure 10 and described below. Numbers in the descriptive list refer to the numbers near the upper left corner of the boxes in the figure.

a. 4-1. Modeling local wave spectra. Local wave generation, refraction, and diffraction over the area of interest were modeled using gulf boundary input waves and wind-field predictions from Step 2.

b. 4-2. Identifying wave breaking effects. Breaking wave zones along delta margins, reef, and shoreline where mass transport and sediment resuspension will occur were located. These effects were introduced where and if necessary.

c. 4-3. Computing near-bottom wave orbital velocities and amplitudes. Maximum wave orbital velocities and orbit amplitudes were computed by application of appropriate analytical expression. These were used to compute a wave friction factor to be employed in sediment transport computations.

d. 4-4. Modeling surface elevations and currents in river, bays, and gulf where necessary. Initial method: Currents and water-surface elevations were computed with the finite element two-dimensional numerical model RMA-2 using the same grid as the sediment model. Storm surges and currents were computed with the finite difference two-dimensional numerical model WIFM. Flood stages were computed with the models described in Step 1-3.

e. 4-5. Modeling salinity conditions. Salinities over the area of interest were predicted for a range of hydrodynamic conditions to show mean and extreme salt concentrations. The TABS-2 dispersive transport model RMA-4 was used.

f. 4-6. Creating hydrodynamic sequences.

   (1) Results desired to be simultaneous were linearly superposed.

   (2) Results were selected or interpolated at time intervals required by sediment models.

   (3) Longer periods of hydrodynamic results were created by sequencing events in representative or statistically prescribed order.

g. 4-7. Computing flow parameters. Hydrodynamic results were used to compute bed shear stress due to currents and waves. The sediment transport was computed by integration of currents over portion of depth.

h. 4-8. Output results. Hydrodynamic and salinity results were displayed in tabular and graphical form for evaluation of

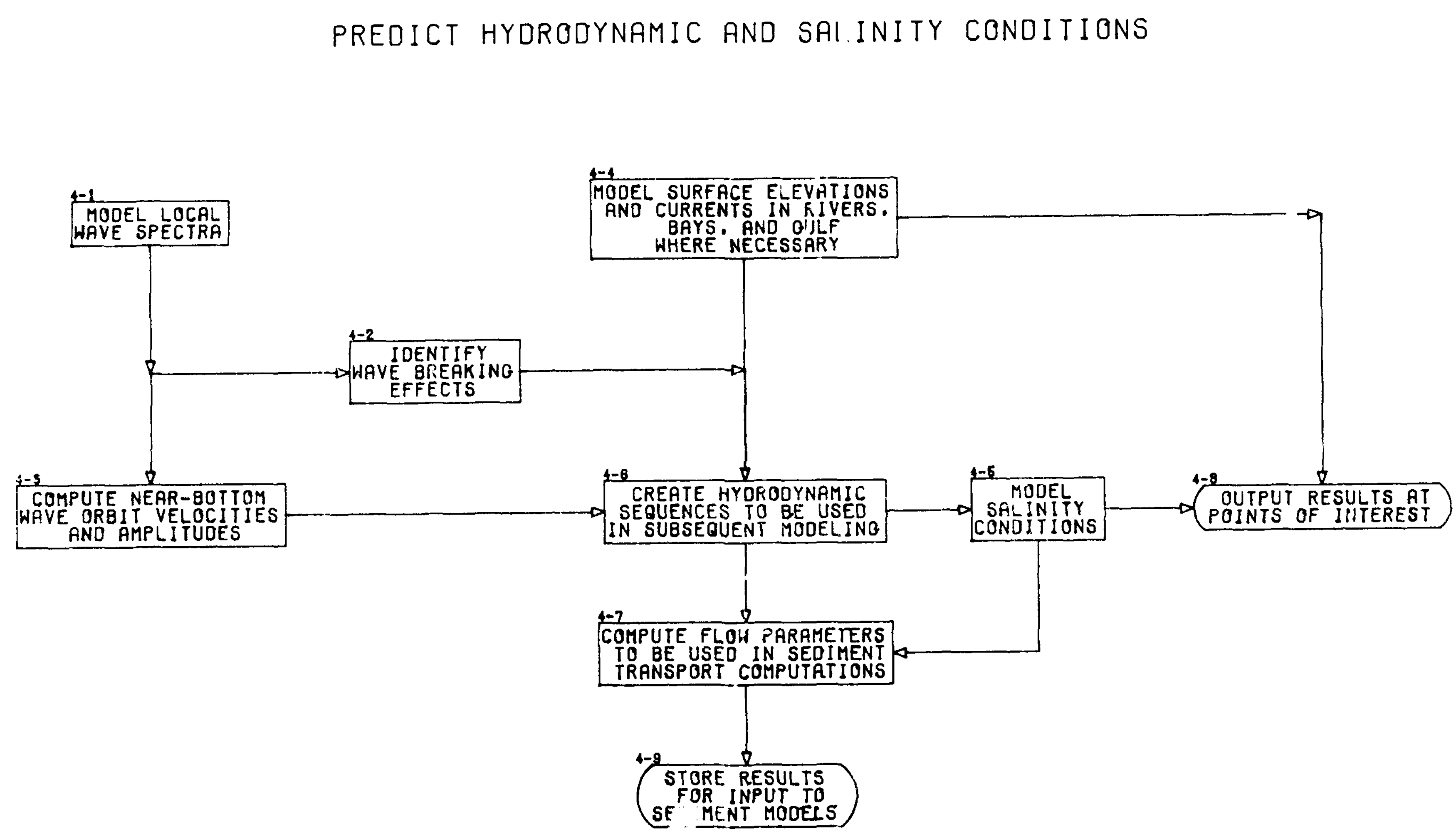

Figure 10. Steps to predict hydrodynamic and salinity conditions

effects for various stages of delta growth and/or possible modifications.

i. 4-9. Storing results for input to sediment models. The results of operations 3-6 and 3-7 were stored in data files for use by the sediment transport models and hot-start hydrodynamic modeling.

Step 5: Predicting sediment transport and growth of the delta

111. Hydrodynamic events created in step 3, were used to calculate sediment transport, deposition, and resuspension by using STUDH, sediment model in the TABS-2 system. Computed deposition and erosion rates at each location in the bay were used to extrapolate bed elevation changes until changes were large enough to significantly influence hydrodynamic response of the bay. The hydrodynamics in step 3, were redefined and the cycle repeated until 50 years simulation was achieved.

Step 6: Presentation of results at desired intervals

112. Results of the several prediction methods were provided to the New Orleans District as they were generated and later published in formal reports.

Implementation

113. The plan was implemented in an orderly, piece by piece approach that added new processes to the effort in sequence if they were shown to have sufficient impact on results to justify the effort. Sensitivity tests and/or field data showed the relative impact of the various processes and provided a basis for either neglecting a process or incorporating its prediction into the solution framework.

PART V: FIELD DATA COLLECTION PLAN

114. Prototype (field) data were collected and analyzed for various aspects of this program and as an independent solution technique. The three main reasons for taking the data were:

- a. To obtain data for verification of the various numerical models and the expanded Atchafalaya Bay portion of the Mississippi Basin Model.
- b. To obtain insights into the relative importance of various energy sources influencing the Atchafalaya Bay and surrounding areas and its dynamic response to these various forcing functions.
- c. To obtain statistics on the different flow regimes influencing the Atchafalaya Bay and surrounding areas.

115. After a comprehensive review of historical data that had been or was being collected in the Atchafalaya Bay area and a tentative selection of solution techniques, the following sequencing of collection was determined to be appropriate for this project. Essentially two sets of data were collected--once during high flow conditions and once during low flow conditions. Some stations were monitored during both flows and the period between them. Long-term (one year or more) monitoring stations were operated (Coleman et al, 1988).

PART VI: SUMMARY OF THE PLAN

116. A plan was designed to predict physical evolution of the Atchafalaya Bay System and some effects of that evolution. The plan employed a variety of analytical techniques, numerical models, and a physical hydraulic model in an integrated solution scheme. By integrating many techniques in a comprehensive approach, the plan permitted inclusion of more physical processes than possible in any single technique. The plan was constructed in modular form so that any technique may be replaced without major impact on other parts of the plan, and to allow orderly implementation of the plan.

117. The plan included the WES DMS-A Data Management System to store, retrieve, and manipulate data, and to display predictions of delta development and bay behavior.

118. Boundary conditions of wind, waves, currents, water-surface elevations, and sediment supply were to be predicted by models and analytical methods.

119. Hydrodynamic conditions were also to be predicted by models and analytical methods. Currents and surface elevations due to tides, winds, and riverflows were considered. Gulf wave parameters for use in sediment transport computations were to be computed for combined waves and currents. Salinities in the bay system were to be modeled.

120. Sediment transport and growth of the delta were to be predicted by five separate methods differing in approach and level of detail. The simplest method extrapolated future delta growth by analyzing past behavior and extending observed growth patterns into the future. Details of sediment transport, deposition, and erosion were to be predicted by the TABS-2 numerical modeling system. Results of the five methods were to be compared for consistency and reasonableness.

121. An extensive field data collection program was included in the plan. Ongoing data collection efforts by the New Orleans District and others were to be supplemented by intensive hydrodynamic and meteorologic surveys.

122. Implementation of the plan was to be performed in an orderly, piece by piece approach. The initial solution framework consisted of simple extrapolation of past behavior. Models and techniques describing other processes were to be added one at a time to this initial framework. The approach provided results at an early date and permitted careful evaluation of each operation before it was added to the production version of the plan.

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Table 1

Atchafalaya-Vermilion Regional Wind Characteristics: Seasonal Frequency of Wind Direction (Expressed as a Percentage), 1951-1960 (from Cunningham, 1978)

	Winter	Spring	Summer	Fall	Annual
N	8.5	6.4	3.8	9.2	7.0
NNE	6.5	4.5	3.2	7.4	5.4
NE	7.6	5.4	5.0	11.4	7.4
ENE	5.9	4.4	4.5	9.0	6.0
E	6.1	5.0	4.8	7.5	5.8
ESE	5.6	5.8	4.9	5.4	5.4
SE	6.8	9.1	6.4	6.4	7.2
SSE	6.3	10.8	6.2	4.8	7.0
S	8.2	12.4	9.8	5.8	9.0
SSW	6.1	7.3	8.8	2.9	6.3
SW	4.3	4.8	7.6	2.4	4.8
WSW	2.0	2.0	3.6	1.0	2.1
W	2.0	1.9	4.0	1.3	2.3
WNW	2.8	2.4	3.2	2.6	2.8
NW	5.0	3.9	3.2	3.2	3.8
NNW	7.1	5.2	2.6	4.8	4.9
CALM	9.4	9.6	17.5	15.1	12.8

APPENDIX A

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